Prudden, (T. M.)

ON BACTERIA IN ICE, AND THEIR RELATIONS TO DISEASE, WITH SPECIAL REFERENCE TO THE ICE-SUPPLY OF NEW YORK CITY

AN EXPERIMENTAL STUDY FROM THE LABORATORY OF THE ALUMNI ASSOCIATION OF THE COLLEGE OF PHYSICIANS AND SURGEONS, NEW YORK

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ON BACTERIA IN ICE, AND THEIR RELATIONS TO DISEASE, WITH SPECIAL REFERENCE TO THE ICE-SUPPLY OF NEW YORK CITY.

An Experimental Study from the Laboratory of the Alumni Association of the College of Physicians and Surgeons, New York.

Our knowledge of the dangers of impure water has become much more precise since we have learned that many common and fatal diseases are caused by tiny vegetable organisms, called bacteria, which such water may contain. As the questions relating to a pure ice-supply are for the most part identical with those relating to the water-supply, in so far as ice is used for drinking purposes, it seems necessary to look for a moment, before passing to the immediate subject of this investigation, at the new methods of water-analysis and the practical advance which their application has brought about.

It was formerly the practice, whenever the fitness of a water-supply for drinking and culinary purposes was called in question, to subject the water, when this was feasible, to a careful chemical examination, and a vast amount of learning and technical skill has been expended in arriving at accurate methods of analysis. But the great difficulty with the simple chemical analysis of water has always been to know exactly what significance to attach to its results. The presence of a considerable amount of organic matter in water, particularly if this could be shown to be of animal origin, has been regarded as a sufficient evidence of its unfitness for drinking purposes. Not because organic matter is in itself unwholesome, but because in the forms of water-contamination it usually signifies decay, putrefaction, or the presence of animal excretion.

More recently, since certain diseases as well as all putrefactions have been shown to be caused by bacteria, the presence of organic matter in drinking-water has been looked upon as indicative of the presence or of the action of these organisms, and in this way furnishes a criterion of the probable salubrity of the water. But chemical examination can determine only inferentially the

presence of bacteria. The new methods of research, however, by which it has been shown that certain diseases, such as consumption, typhoid fever, and cholera, are caused by the presence and action in the body of certain species of bacteria, are directly applicable to the analysis of water. Thus it is no longer necessary to *infer* the presence of bacteria in a given sample of drinking-water from its organic contents, but the bacteria may be actually seen, counted, and their species and actions on the animal body definitely determined. The new method of water-analysis, by which its living bacterial contaminations are determined and studied, is called the *biological analysis.*

It should not be inferred that the biological has superseded the chemical method of water-analysis, but, so far as we can at present judge, it forms a very important addition to it. Indeed, it may be said that, so far as our knowledge of a certain class of bacterial diseases, such as typhoid fever and cholera, is concerned, the biological analysis is the more important; but that this is true in all cases it would certainly be premature to say. For it is already known that in some cases the results of chemical and biological analysis do not coincide. A chemical analysis may, for example, show so large a degree of organic contamination as to render utterly unfit for potable purposes water which at the moment contains comparatively few bacteria. So that it would seem that, in many cases at least, the two methods, mutually supplementary, should go hand in hand.

There are, of course, many cases in which a careful scientific analysis of water is entirely superfluous. When the water is bad-smelling, or when it is obvious that it is mixed with animal excreta, even though it should look clear and colorless, an ordinary common-sense of decency and cleanliness, to say nothing of the danger of incurring disease, should lead to its avoidance for drinking purposes, without some efficient purification. This seems obvious enough; and yet a very little attention to the matter will reveal to the observer instances, sometimes on a large scale, of almost incredible filthiness and foolhardiness in the use of evidently impure water by families and communities which fancy that they are civilized.

A direct microscopical examination of water for the presence of bacteria is impracticable, first, because the individual organisms are so exceedingly minute that it would be almost impossible to examine completely any considerable quantity of water; and, second, because in this way, even if the bacteria could be all seen and counted, we should be unable to determine which of them were living, and as it is only living bacteria which are

capable of inducing disease it is these alone which are of sanitary importance.

The new methods of biological analysis of water are very simple in principle, but require for their execution considerable patience, care, and experience.

The biological method is briefly as follows: In the first place, all the vessels and instruments which will come in contact with our water and the food which we prepare for the nourishment of the bacteria are completely freed from all living germs, which are almost omnipresent in the air and on the things we touch. This is usually done by prolonged heating or steaming. Thus freed from all living things, no matter how small, our materials are said to be *sterilized.* The food which we prepare for the bacteria in water-analysis is usually beef-tea, with a little pepton and common salt and enough gelatin to make it moderately solid when cold. This is called the nutrient gelatin, or culture-medium, and it is poured into glass test-tubes, a few teaspoonfuls in each.

In this medium most of the bacteria which are commonly found in water will readily grow. It is clear and transparent and usually slightly yellowish in color.

Now, one of the prominent characteristics of these lowly organisms, the bacteria, is their capacity, under favorable conditions of nutriment and temperature, of rapid and enormous increase in numbers. This occurs by the slight enlargement of the individual bacteria and their division across the middle into two. These two then each again divide, and so on until within a short time an almost innumerable number of new individuals are produced from the original germ, each one the exact counterpart of its ancestors. It is estimated that, if the conditions are favorable, a single bacterium by this process of growth and subdivision may give rise to more than sixteen and a half millions of similar organisms within twenty-four hours. But so minute are most of these that at an average estimate the whole of these sixteen and a half millions would occupy a space less than the sixteen-hundredth of a cubic inch.

When a water-analysis is to be made, the nutrient gelatin in one of the tubes is melted by gentle heat, and thoroughly mixed by shaking with a measured quantity of the water to be examined. In this way the bacteria contained in the water, always an unknown quantity and of course quite invisible, are evenly distributed through the gelatin. To insure accuracy, duplicate analyses are always made. The quantity of water used is usually one cubic centimetre, and this is taken as the standard quantity in which the bacterial content is expressed.

It should be remembered, in studying the results of the

analyses which are to follow, that one cubic centimetre (1 c.c.) of water is a little less than one-third of a teaspoonful.

The portion of gelatin mixed with the measured quantity of water is now poured out onto a sterilized glass plate, and is spread upon it in a thin, even layer. The plate while this is being done rests upon a level surface kept cool by ice, so that the gelatin soon solidifies. The plate with its gelatin-layer is now put into a clean glass saucer, covered so as to be free from dust, and set away in a moderately warm place.

Now, the single bacteria which are evenly distributed through the gelatin commence to grow, but as they are each inclosed by a solid wall of the nutrient gelatin they grow in a little heap or mass, which is called a "colony." In the course of from two to four days these colonies, each now containing thousands of individual bacteria, have become large enough to be readily visible to the naked eye, or with the aid of a low-power magnifying-glass. We have now only to count these colonies and we know exactly how many living bacteria were present in the one cubic centimetre of water used for analysis, because each visible colony is the result of the growth on the spot of a single invisible bacterium which was caught here by the solidifying gelatin. Of course, if two or more bacteria chance to have clung together when the water was mixed with the nutrient gelatin, our estimate of the number of original germs will be too low, but if the mixture was carefully made this so seldom occurs that the experimental error is slight.

To facilitate the counting of the colonies, a glass plate ruled off into equal squares is usually placed over the gelatin-film, so as not to touch it; and thus, if we do not count all the colonies, we can count those found under several of the squares, and then, by multiplying the average number under the squares which are counted by the whole number of squares, we find the number of colonies, which is the same as the number of living bacteria in the volume of water analyzed.

If we wish to study these bacteria further, which is sometimes of the utmost importance, so as to identify their species, study their effects on animals, and find out whether or not they are disease-producing or pathogenic, we put the glass plate under the microscope, and with a fine, sterilized platinum wire set in a glass handle we take out a minute portion from one of the colonies and put it into a fresh tube of nutrient gelatin, where it will grow until a sufficient quantity of the material is produced for experimentation. Thus, no matter how many different species of bacteria were growing side by side on

the gelatin-plate, we can take out under the microscope a little of each by itself and transfer to separate tubes, and thus get what are called "pure cultures" of all the separate species.

It is always a matter of surprise to one unaccustomed to such an exceedingly delicate mode of water-testing to find what large and varying numbers of these living organisms ordinary water may contain. We usually congratulate ourselves that in New York we have an especially excellent and pure water-supply, and this is in a certain sense true. But a series of thirty-two analyses of the Croton water, as it is delivered through one of the faucets at the College of Physicians and Surgeons on different days during October, November, and December, 1886, and January and February, 1887, shows the lowest number of living bacteria to be 57 to the cubic centimetre; the highest, 1,950; while the average in the thirty-two analyses is 243.

Now, when the first accurate biological analyses of water were made, and the very large numbers of living bacteria which it often contains were noted, it was thought, since certain diseases, and particularly typhoid fever, had been frequently shown to be associated with bad and sewage-contaminated drinking-water; and, furthermore, as typhoid fever and several other diseases were known to be caused by bacteria, that any water which was proved to contain a considerable number of living bacteria was unfit for drinking purposes.

But as our knowledge on this subject has gone on increasing, we have learned that this view must be very materially modified. Bacteria are almost everywhere present, sometimes in enormous numbers, in soil, air, and in parts of the human and animal body which are directly or indirectly in communication with the air or with foods introduced from without. By far the larger proportion of bacteria are, so far as we know, perfectly harmless. Their rôle in nature is to tear down organized bodies into their simpler constituents, a small part of these being used for their own nutrition and growth while the larger part is given up to other organisms for their life purposes. The bacteria are thus indispensable and omnipresent factors in the working out of the organic processes of nature. It still remains true, however, that a certain number of species, which can live in water as well as elsewhere, can and do produce deadly diseases, and are responsible for some of the most frightful epidemics.

Recent researches[1] have shown that there are certain species of bacteria which find in water of the purest kind, even in distilled water, when once they get a footing

there, most favorable conditions for their growth and proliferation, so that it is always necessary to make an analysis of water immediately after its collection, lest we should get as the result of analysis, not the number of bacteria originally in the water, but this number plus those which have grown since it was taken from its source.

Thus Cramer,[2] in Zurich, found that the bacteria in the city water increased in number two thousand seven hundred times in a few days. Leone[3] found that Munich water, containing, when freshly drawn, only five living bacteria per cubic centimetre, after standing for five days held more than half a million. This fact has been confirmed by numerous observers.

These bacteria, which can proliferate in water to an almost incredible extent, and which may be called, *par excellence*, "water-bacteria," are not, so far as is at present known, capable of producing disease in man; but, on the other hand, they have not for the most part been sufficiently studied, so that we can safely assume that they are harmless if taken into the body in large numbers.

Furthermore, some of the bacteria which are known to be the cause of disease in man can grow and increase in number in water, and particularly, as Frankland[4] has shown, in sewer-water, which contains a considerable quantity of organic material which may serve as food.

It is of great importance to know whether the source from which the water to be examined is taken is stagnant, or whether water is running away from it and a fresh supply is flowing in or filtering in through the soil. This is particularly important in wells and lakes; for it is found that a well which has been undisturbed for a time may contain a vastly greater number of bacteria than after a vigorous pumping from it. In a flowing stream, to which a large quantity of pure fresh water is constantly being supplied, this increase of water-bacteria from stagnation is not so important a factor.

Thus it will be seen that the biological analysis of water, important and precise as it is, and apparently leading us directly to the source of many outbreaks of infectious disease, is, after all, beset with many difficulties as soon as we come to the exact interpretation of its results.

At present, the simple statement that a given sample of water contains a large number of living bacteria affords little more just ground for its absolute condemnation than we should have for saying that all flowering plants are unfit for food because a certain number of them are powerful poisons. When we have before us

the numerical results of the biological examination of a given water, the real problem still lies in determining what significance should be attached to them. To solve this we must carefully weigh all the general considerations and facts set forth above. We must find out whether a considerable proportion of the bacteria in the sample are or are not the, at least relatively, harmless water-bacteria which may have grown there; whether the water has been stagnant, or other conditions have existed favoring their increase. We must, above all, find out, if possible, whether there has been a chance for the pollution of the water with sewage or excrementitious matter of any kind. If this be the case, and large numbers of bacteria, not the relatively harmless water-bacteria, be present, we may justly infer that the natural processes of water-purification have not been acting or efficacious, but that the conditions have been favorable for the prolonged existence of the sewage-bacteria, and, among these, of disease-producing forms.

A great variety in the species of bacteria present in a water is rather indicative of sewage-contamination.

Finally, bearing in mind that even very pure spring-, river-, lake-, and well-water may, and frequently does, contain considerable numbers of bacteria, and also that our present knowledge of the disease-producing powers or harmlessness of these ordinary bacteria when taken in large quantities is still very meagre, it seems safe to say in general, for the sake of having some sort of temporary standard until increased knowledge shall give us a more exact one, that any water which contains more than fifty to one hundred living bacteria to the cubic centimetre should not be used without some kind of purification, such as boiling, filtering, etc.

Of course, this number is fixed upon somewhat arbitrarily, and with the sole intention of indicating in a general way what from a bacteriological standpoint may be regarded as a safe rule. Fraenkel, who writes with the approval of Dr. Koch, assumes that good drinking-water should not contain, at most, more than fifty living bacteria to the cubic centimetre. It should always be remembered that absolutely pure water contains no bacteria at all; that which has just been said applies only to apparently pure water. If water is known to be either immediately or remotely polluted with sewage or human or animal excreta, it should under no circumstances be used for drinking purposes without filtration, or some other efficient form of purification, whatever the number of bacteria which it may contain. In any case in which sewage-contamination could be positively excluded from the position and surroundings of the source of the water

so far as our present knowledge goes, the limit of safety might be placed considerably higher.

It is very well known that, by a suitable system of filtration, water which contains so large a number of bacteria as to be entirely unfit for potable purposes may be rendered entirely wholesome; and one of the great practical advantages of the biological and chemical analysis of water consists, not only in the power which it gives us to determine whether or not a given water is fit for use, but also, if filtration is called for, we are thereby enabled to determine positively whether or not the chosen method and practice of filtration is really efficacious.

The so-called spontaneous purification of water by sedimentation or exposure to air will be considered below in so far as it concerns our present theme.

All of the above data concerning bacterial water contaminations and water-analyses apply equally to the problems which ice-impurities present, to which we now turn.

The biological analysis of ice is conducted in precisely the same way as the biological analysis of water, except that the piece of ice to be examined must first be carefully cleansed and then melted. The details of the ice-analyses made by the writer, are as follows: A number of small glass beakers, one for each specimen of ice, were carefully sterilized by heat. A piece of ice about one inch in cube was cracked from the sample lump, and put into one of the sterilized beakers, where it was repeatedly rinsed with boiled distilled water, which by analysis was found to contain no living bacteria. The last rinsing-water was finally drained off, and the beaker set into a hot-water bath until a small portion of the ice was melted; the remaining ice was rinsed with this melted portion, which was then poured off. This operation of rinsing in its own meltings was repeated. It may be safely assumed that in this way the remaining small fragment of ice was entirely freed from any external contamination. Now enough of this for analysis was allowed to melt, and immediately a measured quantity of the water, either one cubic centimetre or one-half this quantity, was mixed with the nutrient gelatin and plate-cultures were made as described above. Duplicate analyses of either of the above quantities were made for the purpose of control; the smaller quantity was used only when there was reason to suspect that the ice contained many bacteria, as in this case the counting of colonies in a larger dilution is more readily and accurately done. In every case the water from the melted ice was used within five minutes of its melting, so as to preclude the possibility of an increase in the number of bacteria, as mentioned above.

It should be stated here that samples of ice which contained evident gross impurities, such as grass, straw, particles of sand, leaves, etc., were in all cases rejected as not fairly representative for analysis. Such ice is ordinarily carefully excluded from the harvest by the more responsible companies, but sometimes, particularly when the crop is short, as was the case during the last winter, does not infrequently find its way to the doors of consumers.

It is a popular belief that water in freezing purifies itself, so that water which would be unpalatable and seem unfit for drinking purposes may be regarded as quite pure when frozen. This belief is to a certain extent true, or, rather, rests upon a basis of truth; for, as is well known, coarser foreign particles may be to a certain extent thrown out in the act of freezing, and the same is true in more marked degree of certain inorganic salts, coloring materials, etc., held in solution. The beautiful clearness and sparkle of well-formed ice tends to confirm the belief that the act of freezing is a very perfect purifying agency. It has, however, been shown that, so far as organic matter in solution is concerned, freezing by no means entirely purifies the water.

As is well known, the vitality of quite highly organized beings, such as toads, frogs, worms, etc., is said to be not infrequently retained during a prolonged enclosure in ice, and stories of a more or less sensational nature concerning the discovery of such beings in ice are common enough in the newspapers. But these are exceptional cases, interesting only as facts in biology, and have no practical bearing whatever upon the purity of ice in general.

In regard to the bacteria, it should be remembered that they are so exceeding minute that they may exist in water in enormous numbers without in the slightest degree impairing its clearness and transparency. Thus a series of experiments on the typhoid-fever bacteria by the writer showed that more than one and a half million of these organisms may be diffused through a tablespoonful of perfectly clear distilled water without in the least appreciable degree impairing its transparency as it is held to the light in a thin-walled glass tube half an inch in diameter. By passing a beam of light from a lens through the tube the faintest opalescence was detected.

The literature on the subject of the effect of cold on bacteria is not extensive, especially by the use of the modern methods. These enable us not only to tell whether or not all of the bacteria exposed to cold are destroyed—which was about all the older methods could do [5]—but they enable us to tell just how many are killed

by a given exposure, and what species are most vulnerable, either in a mixture or in pure cultures.

It was shown by Cohn,[6] more than a decade ago, that certain bacteria were capable of retaining their vitality after an exposure of several hours to a very low temperature, in one case to 0° F., and similar observations have been repeatedly made.

Pengra,[7] in 1884, apparently by the method of simple microscopical examination, concluded that as regards bacteria in water there may be a purification of about ninety per cent., but his method of working would suggest the possibility that a part, at least, of this purification might, in his experiments, be due to the simple sedimentation of the bacteria before or during the freezing.

In a recent report to the State Board of Health of New York, on the purity of ice from several sources, by James T. Gardiner,[8] experiments made by Hailes at his request showed that ice may contain considerable numbers of living bacteria. This general observation has been repeatedly made.

The first complete and accurate series of biological analyses of ice were made in Berlin, Germany, less than a year ago, by Fraenkel.[9] His experiments show that while the number of living bacteria contained in a given sample of water is often greatly reduced by freezing, sometimes as much as ninety per cent. in three or four days, yet that the resulting ice may still retain large numbers when the water is greatly contaminated with them.

Experiments showing the Effect of Freezing on Separate Species of Bacteria.—In order to find out exactly what the effect of freezing is on isolated species of bacteria suspended in water, a series of laboratory experiments was carried out by the writer as follows: A large number of test-tubes were plugged at the mouth with cotton and thoroughly sterilized. These were divided into sets, and into each tube of the different sets was put about five cubic centimetres of sterilized water which had been mixed with a small quantity of a pure culture of some well-defined species of bacteria. Before these mixtures were put into the tubes the number of bacteria contained in one cubic centimetre of the water was determined by the usual method of water-analysis. Duplicate analyses were made, to insure accuracy. Into each set of tubes a different species of bacteria was introduced. In this way we have in each set of tubes water contaminated with one species only of bacteria, and the number of these in each cubic centimetre definitely known. These tubes were now put into a refrigerator, the temperature of which was kept by ice and salt at from 14° to 30° F. The water in the tubes was usually

frozen solid in a short time. The refrigerator was kept at this temperature for three months, and the tubes containing the different kinds of bacteria were taken out at varying intervals, the ice in them melted, and the number of living bacteria in one cubic centimetre determined in the usual way. By comparing the number of bacteria found in one cubic centimetre of the water after the freezing with that in one cubic centimetre before freezing, we have an exact determination of the number destroyed.

More than one hundred complete analyses were made in this way, and the effect of longer or shorter freezing studied on six species of bacteria under varying conditions.

The species used were: 1. Bacillus prodigiosus. 2. A short bacillus, frequently found in the Hudson River water and occasionally in the ice, which is apparently identical with the Proteus vulgaris of Hauser. 3. A slender bacillus very common in Croton and other waters, fluidifying the gelatin in sharply circumscribed pits. 4. The micrococcus of suppuration, called Staphylococcus pyogenes aureus, which was derived from a case of pyæmia. 5. A short bacillus very common in ice from all the sources about New York, as well as in the waters from which it is obtained. This bacillus is especially characterized by producing a beautiful greenish fluorescence in the gelatin, which it does not fluidify. We may call it for our purposes the fluorescent bacillus. 6. The bacillus of typhoid fever.

Owing to its great importance, the most extended study was made upon the bacillus of typhoid fever; more than fifty analyses having been made to determine the effect of freezing upon it under varying conditions. It does not seem necessary to give the figures obtained in each case, but, except in the cases of the typhoid-fever bacteria, to simply summarize the results obtained.

TABLE I.—*Bacillus prodigiosus.*

Time.	Number of bacteria in 1 c.c. of water.
Before freezing	6,300
Frozen 4 days	2,970
Frozen 37 days	22
Frozen 51 days	0

In this species it will be seen that the number of living individuals is largely reduced at first, but that a small number remain alive after more than one month. Another set of experiments on this species, whose results are given in Table IX., is interesting in comparison with this.

TABLE II.—*Proteus vulgaris* (*Hauser*).

Time.	Number of bacteria in 1 c.c. of water.
Before freezing	8,320
Frozen 18 days	88
Frozen 51 days	0
Frozen 65 days	0

Although in this set of experiments the Proteus vulgaris was completely destroyed after at least fifty-one days' freezing, this is not invariably the case, because it occasionally develops on the plate-cultures made from Hudson River and other ice in small numbers. The significance of this we shall consider farther on.

TABLE III.—*Slender Fluidifying Bacillus from Croton Water.*

Time.	Number of bacteria in 1 c.c. of water.
Before freezing	800,000
Frozen 7 days	0
Frozen 18 days	0
Frozen 38 days	0
Frozen 47 days	0

This species also, while completely destroyed by the artificial freezing, is occasionally found in considerable numbers in natural ice from all sources.

TABLE IV.—*Staphylococcus pyogenes aureus.**

Time.	Number of bacteria in 1 c.c. of water.
Before freezing	Innumerable
Frozen 18 days	224,598
Frozen 20 days	46,486
Frozen 54 days	34,320
Frozen 66 days	49,280

The culture from which this series of experiments on Staphylococcus was made was fresh and actively growing on agar. Another similar series was prepared, but from an old and partially dried agar-culture. In this the original contained 162,000 bacteria to one cubic centimetre, which grew readily on the gelatin plates. The tubes stood in the refrigerator unfrozen over night, but froze early in the morning. When examined after being frozen five and seven days, not a single living bacterium was found.

Lübbert[10] has recently shown that all the individuals in a gelatin culture of Staphylococcus are not killed by twenty-four hours' freezing. The individuals in a four weeks old agar culture were all destroyed after twenty hours' freezing.

* Compare Table VIII.

TABLE V.—*Fluorescent Bacillus from Hudson River Ice.*

Time.	Number of bacteria in 1 c.c. of water.
Before freezing	Innumerable.
Frozen 4 days	571,560
Frozen 11 days	520,520
Frozen 51 days	183,040
Frozen 65 days	10,978
Frozen 77 days	85,008

In this species, as will be seen, there is considerable variation in the vulnerability of the individuals, as the number destroyed by freezing does not uniformly increase as the action of the cold is prolonged. This is not surprising, however, when we reflect that, although coming from the same culture, the individuals in the culture would vary both in age and nutritive conditions and that the chances are altogether against an equal distribution in the different tubes of hardy and vulnerable individuals.

This, it will be seen, is not exterminated like the previously examined species, and its invulnerability is also shown by the great frequency with which it occurs in our New York ice.

TABLE VI.—*The Bacillus of Typhoid Fever.*

Time.	Number of bacteria in 1 c.c. of water.
Before freezing	Innumerable.
Frozen 11 days	1,019,403
Frozen 27 days	336,457
Frozen 42 days	89,796
Frozen 69 days	24,276
Frozen 77 days	72,930
Frozen 103 days	7,348

The culture from which the above series of experiments was made was actively growing on agar. As the original number was so large the percentage rate of destruction is not evident, nor does it appear what the effect of the first few days' freezing is. For these reasons another series was prepared from an active gelatin culture, which gave the following results :

TABLE VIA.—*Bacillus of Typhoid Fever.*

Time.	Number of bacteria in 1 c.c. of water.
Before freezing	378,000
Frozen 12 hours	164,780
Frozen 3 days	236,676
Frozen 5 days	21,416
Frozen 8 days	76,032

The experiments on the typhoid bacillus of Table VI. were repeated, using about the same quantity of the contaminating mixture but replacing the distilled, sterilized water with the sterilized Croton, which contains more organic matter and which, therefore, more nearly approaches the conditions of natural ice. As was to be expected, however, the results were essentially the same. With innumerable bacilli in one cubic centimetre before freezing, after being frozen solid for sixty-five days one cubic centimetre contained 26,950 living bacteria.

We thus see from the experiments on this most important species, that after prolonged freezing a considerable number of the bacteria remain alive.

Billings[11] has recently shown that all the individuals in a typhoid bacillus culture suspended in water are not killed by being frozen over night.

A series of experiments was made by sowing on gelatin plates, side by side, the bacilli of typhoid fever which had just been frozen in water and those taken from a fresh gelatin culture. These invariably showed that the growth of the frozen bacteria was at first much slower than that of the unfrozen, but when the colonies were once fairly started they went on at about an even rate of growth.

Experiments on the Alternate Freezing and Thawing of Bacteria Suspended in Water.—The fact that a very considerable reduction in the number of viable individuals occurs at the first freezing, while a more gradual destruction goes on as the low temperature is maintained, is doubtless due to the killing off at once of the more feeble bacteria. Still it would be interesting to know whether the marked rate of destruction is due to this factor alone, or whether the sudden change of temperature may not have a greater effect than a simple prolongation of the unfavorable condition when once the organisms have accustomed themselves to it.

With a view of throwing light upon this point a series of experiments was executed, the results of which are shown in the following tables. A number of tubes of sterilized water were inoculated with the same number of bacteria from the same source—a fresh, actively growing gelatin culture of the typhoid bacillus. A part of these were frozen solid at once, and remained so until they were removed from the refrigerator, one by one, at varying intervals, and the number of living bacteria in each determined. The second set of tubes was treated in the same way, except that the water was repeatedly frozen and thawed before examination, the number of times this thawing was repeated varying with different tubes, as shown in the table.

TABLE VII.—*Result of Alternate Freezing and Thawing on the Typhoid Bacilli—Fresh Active Culture.*

Frozen solid and remained so.		Frozen solid, but repeatedly thawed and immediately refrozen.	
Time.	Number of bacteria in 1 c.c. of water.	Number of times thawed and refrozen.	Number of bacteria in 1 c.c. of water.
Before freezing	40,896	....	40,896
Frozen 24 hours....	29,780	3	90
Frozen 3 days......	1,800	5	0
Frozen 4 days......	950	6	0
Frozen 5 days......	2,490	6	0

Similar experiments were made with the Staphylococcus pyogenes aureus and with the Bacillus prodigiosus, with the results shown by the following tables :

TABLE VIII.—*Result of Alternate Freezing and Thawing on the Staphylococcus pyogenes aureus—Fresh Active Culture.*

Frozen solid and remained so.		Frozen solid, but repeatedly thawed and immediately refrozen.	
Time.	Number of bacteria in 1 c.c. of water.	Number of times thawed and refrozen.	Number of bacteria in 1 c.c. of water.
Before freezing	111,782	....	111,782
Frozen 15 minutes..	[illegible]	....	....
Frozen 2 hours.....	21,300	....	....
Frozen 24 hours....	22,690	1	13,495
Frozen 48 hours....	6,460	3	110
Frozen 96 hours....	6,155	4	0

TABLE IX.—*Result of Alternate Freezing and Thawing on the Bacillus prodigiosus—Fresh Active Culture.*

Frozen solid and remained so.		Frozen solid, but repeatedly thawed and immediately refrozen.	
Time.	Number of bacteria in 1 c.c. of water.	Number of times thawed and refrozen.	Number of bacteria in 1 c.c. of water.
Before freezing	339,516	....	339,516
Frozen 24 hours....	36,410	1	2,570
Frozen 30 hours....	41,580	2	275
Frozen 48 hours....	14,440	3	15
Frozen 96 hours....	4,850	4	0

These experiments on the bacillus of typhoid fever, Staphylococcus pyogenes, and Bacillus prodigiosus show that the greatest destruction occurs during or shortly after the sudden reduction of temperature to the freezing point of water, and that if after this the bacteria

remain in the ice a comparatively gradual destruction goes on ; but that if now the bacteria be thawed out and immediately refrozen another large increment is destroyed. In this way, by repeated freezings and thawings, the bacteria may be completely destroyed in a short time.

It would seem that at the time of freezing a certain number of the bacteria are killed outright, while the vital ity of the remainder is considerably reduced. Now if these bacteria with reduced vitality are placed under favorable conditions of temperature and nutrition, as in the culture-gelatin, they can grow and proliferate in the usual way, while on the other hand they have not vitality enough to resist subsequent freezings.

The conditions under which the last series of experiments on the freezing and thawing of bacteria was carried out differ from those which have preceded them in that, in order to hasten the freezing, the tubes were immersed directly in a mixture of ice and salt, which gave an average temperature of from 2° to 5° F. below zero, so that they were frozen at once. They were then placed in the refrigerator, where the temperature was just below 32° F., and kept here with those which remained solidly frozen until they were again thawed or removed for examination. The ordeal was therefore in this series of experiments much more severe than in any of the others. A comparison of the general destruction-rate of bacteria frozen at this low temperature and those frozen at a higher degree shows, as would be expected, a considerably larger destruction ratio with the lower temperature. This may have a practical bearing, for it may well be true that Maine ice and Norwegian ice, which is largely used in England, may be much freer from living bacteria on this account.

Experiments on the Effect of Low Temperatures on Bacteria Suspended in Water when the Water does not Crystallize.—A very considerable destruction of bacteria of various species takes place if the water be placed in a very cold place, but kept just above the freezing-point. Thus, in a considerable number of experiments, a much larger number of individuals was destroyed in tubes in which the water did not freeze, although kept several degrees below the freezing point, than in those in which it became solid. These conditions were obtained by coating the inside of a number of test-tubes with sterilized sweet-oil, and then putting into them the water containing the bacteria. These tubes, together with others prepared without the oil, were placed side by side in the refrigerator. After a few hours, the water in the larger part of the tubes whose sides had been

rendered quite smooth by the coating of oil would be found unfrozen, while that in the others would be solid. This difference is obviously in accordance with a well-known physical observation, *i.e.*, that fluids crystallize more readily when in contact with rough than smooth surfaces, and that small quantities of water kept perfectly still may be carried considerably below the freezing-point without solidifying. The previous boiling of the distilled water used in these experiments, by the removal of its contained air, contributes to the avoidance of freezing at low temperatures.

As an example of these experiments, which are not given here in detail as they do not concern directly the present study, tubes were placed side by side in the refrigerator which both held water containing the staphylococcus, 111,782 to the cubic centimetre; one tube was oiled within, the other not. After eighteen hours, during which they were kept perfectly quiet at from 15° to 28° F., the water in the oiled tube was fluid, in the other solid. Analysis showed that the water which had frozen contained 81,940 living bacteria to one cubic centimetre, while that in the other tube, which had not frozen, contained 16,400 to one cubic centimetre. Even the very hardy fluorescent bacillus can be readily destroyed if the water in which it is diffused is thus reduced to a very low temperature, but kept from crystallizing.

In these experiments the tubes must be removed carefully from the cold chamber if the temperature is very low, lest they should suddenly crystallize from sudden jarring.

This difference in the destructive capacity of what may be called dry cold and moist cold is interesting in view of the similar difference which exists at the other end of the thermometric scale, between moist and dry heat.

Summary of the Effect of Low Temperatures on Pure Culture of Bacteria Suspended in Water.—The laboratory experiments thus far recorded on the action of prolonged low temperatures on various species of bacteria suspended in water and frozen show, so far at least as the species employed are concerned: 1. That a considerable number of the bacteria are, in all cases, killed by freezing. 2. That the number killed depends upon the condition of vitality of the individual at the time of freezing. If the vitality is lowered, as by the exhaustion of nutriment in the culture, drying, etc., a larger proportion will be destroyed than if the nutrient and other conditions preceding the freezing are favorable. 3. That different species differ widely in their power of retaining life at the temperature at which water freezes and below. While some species, such as Bacillus prodigiosus, Proteus

vulgaris, and the fluidifying water-bacillus, are nearly completely or entirely destroyed after a comparatively short freezing; others, such as the fluorescent bacillus, the Staphylococcus pyogenes, and the typhoid bacillus are so tenacious of life that a large number of the individuals may remain capable of growth even after long periods. This is especially significant, for obvious reasons, in the case of Staphylococcus and the typhoid bacillus, which are capable of producing serious disease. 4. That the time during which the low temperature is maintained is of importance in determining the number of bacteria of any given species which will be destroyed. For, so far as the experiments have gone, it appears that after the first freezing, at which time the destruction seems to be most extensive, a more gradual death of individuals occurs as time goes on. What the limits are to this gradual destruction does not appear from these experiments, as they have been extended only to the one hundred and third day in the case of the typhoid fever organism. 5. The unequal percentage destruction which, as appears in the tables showing the action of cold on different specimens of the more resistant species, shows that in a given culture the individuals are not equally capable of resisting the effects of low temperatures. This is what would be expected when we remember that in an actively growing culture of any bacterial species the age of the individuals, as well as the conditions favorable to their nutrition, will vary widely on account of their massing together as the growth of the colony proceeds. 6. By alternate freezing and thawing bacteria are more largely destroyed than when exposed to a sustained low temperature. If a low temperature be maintained in the water, while the latter is not permitted to freeze, a greater destruction occurs than when crystallization occurs.

It should be noted here that in these experiments on the artificial freezing of the bacteria that the test is considerably more severe than that to which the bacteria are subjected under the ordinary natural conditions of river and lake waters in this latitude, because the change of temperature is more abrupt, and at times the cold more severe. It was found impossible, with the facilities at the writer's command, to maintain a uniformly low temperature, as for a time after the refrigerator was restocked with ice and salt the temperature would fall to 14° F. and gradually rise to just below the freezing-point of water.

The importance of this change of temperature will be more evident when we see the results of the next series of experiments.

EXPERIMENTS ON THE ARTIFICIAL FREEZING OF NATURAL WATERS CONTAINING BACTERIA.—While, by the above method of experimentation on single species of bacteria from pure cultures, we can obtain much more precise knowledge of the effects of freezing than in any other way, there is a good deal of practical importance in knowing about what percentage of the mixed bacteria as they occur in natural waters are destroyed in the formation of ice. Now the examination of the water from a given pond or river, and the ice formed from it in the natural way, does not, even if the water be taken in winter when the ice is forming and both are taken from the same place, give a very accurate destruction-percentage, because the water beneath is always more or less in motion, and in both water and ice there is a very unequal distribution of the bacteria. Thus we might have a sample of ice which contained either a much greater or a much smaller number of bacteria than that present at the time of collection.

Approximate accuracy may, however, be obtained by collecting, under suitable precautions, waters from various sources in winter, and, after determining from each sample the average number of bacteria, freezing the remainder, and, after analyzing the ice, comparing the results.

This the writer has done, choosing as types of water samples from: 1. A large, fairly good water-system of ponds, lakes, and larger and smaller streams—namely, from the Croton water as delivered through the pipes during November, December. January, and February of the winter of 1886–7. 2. Van Cortland Pond, a small, comparatively still, shallow pond, fed by springs and small streams. This water was collected in January, 1887, from beneath the ice near the outlet and at the upper end of the pond. 3. The Hudson River, a large tidal stream, with abundant sewage pollution. The water from this source was taken in January, 1887, from beneath the ice just off Kingston Point, which projects far out into the stream. This is not far from fifty miles below Albany, and at the time of collection the tide was ebbing. This would seem to be a fair sample of water from the lower Hudson.

All of these samples were collected by the writer in small sterilized bottles, such as are usually employed for this purpose. Immediately after collection the samples were brought to the laboratory and the examination at once begun. In the case of the Hudson River water three hours passed in the journey home, but the water in the mean time was kept cold. This is important, because the possibility of a multiplication of the bacteria in transit would seem to be excluded.

TABLE X.—*Artificial Freezing of Croton Water.*

Sample I.			Sample II.		
Number of bacteria in 1 c.c. of water before freezing.	Number of days frozen.	Number of bacteria in 1 c.c. of melted ice.	Number of bacteria in 1 c.c. of water before freezing.	Number of days frozen.	Number of bacteria in 1 c.c. of melted ice.
168	4	80	1,950	3	242
168	69	[illegible]	1,950	11	84
168	74	49	....	..	...

TABLE XI.—*Artificial Freezing of Water from Van Cortland Pond.*

Sample I.			Sample II.		
Number of bacteria in 1 c.c. of water before freezing.	Number of days frozen.	Number of bacteria in 1 c.c. of melted ice.	Number of bacteria in 1 c.c. of water before freezing.	Number of days frozen.	Number of bacteria in 1 c.c. of melted ice.
2,621	1	480	732	1	162
2,621	3	436	732	3	278
2,621	8	363	732	8	99

Sample I. was taken from the pond near the outlet. Sample II. from the upper end.

TABLE XII.—*Artificial Freezing of Water from the Hudson River off Kingston Point.*

Sample I.			Sample II.		
Number of bacteria in 1 c.c. of water before freezing.	Number of days frozen.	Number of bacteria in 1 c.c. of melted ice.	Number of bacteria in 1 c.c. of water before freezing.	Number of days frozen.	Number of bacteria in 1 c.c. of melted ice.
3,448	2	720	3,056	2	156
3,448	11	62	3,056	6	302
3,448	16	324	3,056	6	200

The numbers of bacteria killed by freezing, as will be seen, vary so much in different samples and even in different specimens of the same sample that we can arrive in this way only at very general results. This variability depends largely, as would seem from the above series of laboratory experiments, upon the varying number of different species of bacteria which any given sample contains, as well as upon the varying degrees of vulnerability of individuals of the same species. We may, however, say in general that water containing bacterial contaminations by freezing, and remaining frozen for a few days,

may purify itself by the destruction of as much as ninety per cent. of the bacteria. Furthermore, the number of living bacteria is gradually reduced in the ice as time goes on, but that this reduction does not go on to extinction, for all species at least, will be seen from the analyses of natural ice which are to follow.

Having thus established experimentally a variety of facts regarding the purification of water from its bacterial contaminations by freezing, let us now turn to the natural ice which is supplied to New York City from various sources.

Description of Sources of the Ice-supply of New York City.—The ice which is supplied to New York City, and to a certain extent to Brooklyn and Jersey City, comes almost entirely from three sources—from the Hudson River, from a few lakes and ponds adjacent to the Hudson or near the line of some of the suburban railways, and from Maine. The Hudson River stands foremost as a source of supply, the outlying lakes and ponds furnishing in comparison but a moderate quantity, while the Maine supply is drawn upon, as a rule, only when the ice season in this region has been a poor one and the domestic stock runs low. The competition in the ice market is so sharp and the margin of profit usually so close that the increased cost of transportation from Maine and the liability to wastage in transit are sufficiently potent factors to largely shut the Maine product out of competition if plenty of ice is in storage nearer by.

The total storage-capacity of the ice-houses along the banks of the Hudson from Troy to Poughkeepsie reaches the enormous amount of more than three million tons. The storage-capacity of the houses which draw their supply from lakes and ponds near New York is about three hundred and forty thousand tons. Besides this, in good ice years a considerable quantity is frequently stacked outside the houses for use early in the season.

Let us now look more closely at the bodies of water from which the New York ice-supply is obtained, and first at the lakes and ponds.

Among these *Rockland Lake* stands foremost both in the popularity of its ice and the quantity which it furnishes. The traveller by the New York Central Railroad, looking from the car-windows across the river at Sing Sing, will usually see clustered at the foot of the cliffs a number of white, clumsy craft with slender derricks and awkward windmills set upon their decks. These are ice-barges. Just over the summit of the hill at this point lies Rockland Lake, a lovely sheet of water set in a little basin on the western slope of the hills

which thrust themselves forward into the river here and form the upper limit of the Tappan Zee.

The lake is in part shallow, but in some places has considerable depth ; its shores are open, and the water is supplied almost entirely from springs which drain the hill-sides surrounding it on the north, east and south, those on the east or river side sloping abruptly down to its shore. It is a lake, the situation and general appearance of which would impress the writer with its natural fitness for a source of water- or ice-supply.

The ice is stored in large houses on its banks, and these have a capacity of about one hundred and fifty thousand tons. During the shipping season the ice is loaded into cars at the house, drawn by steam up a short incline and lowered down a longer incline on the river side of the palisade to the barges.

A little village lies in the break in the hills over which the inclined railway passes, and, unfortunately, some two-score of small dwellings with the ordinary outhouses are built on the steeply sloping hill-side which extends, only a few rods away, to the edge of the lake.

The possibility that the drainage from these dwellings may reach the lake without that thoroughness of soil-filtration which a strict attention to hygiene demands, seems worthy of consideration. The lake is used for boating in summer and for skating in winter.

Swartout Pond.—On the little brook which carries the surplus water from Rockland Lake off into the Hackensack River lies this small, shallow pond. The shores are for the most part clear and open, and the ice-house has a storage capacity of about fifteen thousand tons.

The ice gathered from these two sources is of especial value to the company controlling them, owing to their nearness to New York and the facility of transportation by rail or water during the cold months when the river above is frozen and navigation is at a standstill.

Highland Lake.—This little picturesque body of water, perched on the hill-side just below Fort Montgomery, and supplied by springs from the high, wooded hills which lie behind it, is an ideal source of ice-supply. No dwellings, barns, or other sources of contamination are near it, and the water is deep and clear.

The ice is run from the shore of the lake directly down a series of inclines into the storage houses beside the West Shore Railroad and the Hudson River, so that by the force of gravity alone the ice may be carried from the lake to the houses and thence to the cars or barges. A considerable stream runs from the lake in winter. During the months in which this investigation

was in progress, ice from this source was not being delivered in New York, and hence no analyses were made of it. Like most pond and lake ice, it usually contains numerous scattered bubbles, but its source is so clean and pure that there seems every reason to rely upon its excellence.

Pond on Verplank's Point.—Here, some twelve years ago, a large swamp, through which ran a small brook draining the region toward Montrose, was converted into a shallow pond by a low dam built just at the river's edge. The water-level in this pond stands some feet above that of the Hudson River at high water, and a sluice-way, controlled by a gate, allows of the nearly complete emptying of the water. In the autumn, when, as the writer's informant graphically expresses it, "the pond has got done purging itself"—by which is meant the collection of dirty scum and a variety of dead vegetable matter on the surface after the hot weather—the water is drawn off, and the pond fills anew. A small quantity of water runs over the sluice-way in winter, and no sources of contamination were observed on the shores. The pond is called "Lake Meahaugh," and the storage-capacity of its houses is about sixty-five thousand tons.

Ice Pond or Hinkley's Pond (*so-called* "*Croton Lake*"). — This shallow pond, covering a few acres, lies on the line of the Harlem Railroad, between Dykeman's and Towner's, a little more than fifty miles from New York. The pond is mainly supplied by springs from the surrounding hills, but there is a small inlet and a small outlet, which forms one of the sources of the Croton River. The banks are open and free from trees, and, with the exception of the ice company's barn, free from buildings or other obvious sources of outside contamination.

The pond was apparently at one time considerably larger than it is at present, but its lower end has become filled and is now a swamp, in which water at the level of the lake surface is standing, and out of which comes a bushy undergrowth and a considerable number of small, stunted trees. This feature is important, as the pond-water, although open and drained by a small running stream, is indirect connection with—is, in fact, a part of—a large swamp containing much stagnant water.

Van Cortland Lake.—This small lake, or, more properly speaking, pond, lies about four miles above High Bridge, on the line of the New York City & Northern Railroad, and within the limits of the new Van Cortland Park. It is not very deep, and is of a few acres in extent. The water is held in place by a small dam furnishing power for an old grist- and saw-mill, and is used

for ice-cutting and skating purposes in winter, and, to a certain extent, for boating in summer. Its banks are open and apparently tolerably free from external sources of contamination.

There is a small overflow, and the water is supplied in part from springs, in part from small streams, one of which runs through a long woody swamp, which is in communication with the pond at its upper end. The ice-houses hold about seven thousand tons. While much of the ice cut here is delivered in the upper part of the city, its nearness and situation on the railroad make it available for a winter supply to dealers whose stock on the Hudson is cut off by the close of navigation, and a varying quantity is shipped to New York and other places without housing.

Tuckahoe.—The Bronx River, at the village of Tuckahoe, is dammed, to furnish a part of the power for a rubber mill located here, and the small, rather shallow pond which sets back and eastward to the Harlem Railroad, supplies ice for the houses, containing about twenty thousand tons, and for direct shipment in winter.

Ice from this source, together with that cut on Ice Pond, furnishes the so-called "Croton Lake Ice." *

The Tuckahoe Pond shares in the virtues and faults of the lower Bronx, which passes several villages above. A suitably authorized system of inspection would doubtless suggest the desirability of placing the ice company's barn at a greater distance from the shore of the pond, and the removal farther from the water's edge of three out-houses belonging to dwellings near by. It should be added, however, that the vaults of these out-houses are said to be cemented.

Lake Mahopac.—On this lake arrangements have been made for ice-harvesting, and a large house, capable of holding about thirty thousand tons, stands beside the New York City & Northern Railroad, within easy distance of the lake. The ice from this source is not, however, at present in the market, owing, as the writer is informed, to the cost of transportation to New York. Its quality was therefore not investigated.

There are also harvesting facilities at Greenwood Lake.

The Hudson River.—We now come to the great and most important source of our ice-supply—the Hudson River. We should remember at the outset that this majestic stream is, in fact, a great estuary of the sea, and that its impressiveness as a large body of water and its importance in navigation are largely due to its tidal

* No ice is cut for the market on the reservoir lake known in the geographical sense as Croton Lake.

connection. The water is brackish at times as far up the stream as Poughkeepsie; and the influence of the tide is felt by a rise of more than a foot at Albany. The fall of the river from Albany to New York is so slight that at times the current at Albany is reversed and runs northward for some hours.

The main ice-harvesting fields lie between Poughkeepsie and Troy, and their exact location within these limits is determined by a variety of conditions, such as dockage facilities, currents, widenings in the river, ownership of water-front, etc. The water must be deep enough, so that the ice will not be contaminated from the bottom by grass, sand, etc. Areas of water in which the currents are not too strong are sought after, as during mild winters the requisite thickness of ice is more certain to form where the currents are not excessive. In prolonged cold weather, however, the river freezes completely over, so that ice may be cut in the deeper channels as well as elsewhere.

The river is, at best, rather shallow for purposes of navigation in its upper portions, and large quantities of detritus, which are annually brought down the stream, cause a constant and often considerable change in the bottom, so that each spring the river must be resounded and buoyed. A glance at the map of the upper part of the region which concerns us, say from Coxsackie to Albany, or even a study from the car-windows, shows in the river a very large number of large and small, low, irregular islands scantily covered by a stunted vegetation.

These islands, a gradual formation from sedimentary deposit, indicate the shallow character of the stream, which, in this region, is virtually a long, narrow archipelago. An extensive system of dikes has been built for the purpose of deepening the navigation channel, and behind these lie large areas of comparatively still water.

Let us now look at the character of the water which the Hudson bears within the limits of the ice-harvesting region. At the upper part of this section is Troy, a city of over fifty thousand inhabitants, emptying its eight million gallons of sewage daily into the river, already charged with contributions from Cohoes and Lansingburg, to say nothing of the impurities which the Mohawk brings with it from the west. A few miles below Troy lies Albany, with over ninety thousand inhabitants, and an efficient sewage system which pours directly into the river. These are the great sources of pollution of the river water.

Hudson with over eight thousand inhabitants, Catskill with more than four thousand, and Kingston with more

than eighteen thousand, add their greater or less sewage contributions within the ice-field limits, to say nothing of numerous smaller towns which drain into the river.

It would seem hardly necessary to do more than mention the fact that a city of the size of Albany empties its sewage into a stream whose waters a short distance below are used in the form of ice for drinking purposes, unfiltered, to cause a universal condemnation of the practice. It is estimated by Mr. Sweet, as quoted by Dr. Chandler in his report on the water of the Hudson River in January, 1885, that the average daily flow of the Hudson at Albany amounts to 6,677,000,000 gallons. The amount of water pumped from the river for the use of the city of Albany amounts, on the average, to 6,064,000 gallons daily. This, of course, is largely returned to the river as sewage. The Hudson River just below Albany thus consists of about 1,100 parts of rather dirty river water from Troy, and one part of Albany sewage. A series of chemical analyses by Mason, made at the request of the Board of Health of Albany, showed : "First, the influence of the addition of Troy sewage is felt in the river just below Troy ; second, there is no material change for the better by the time the water reaches Albany."[12]

A slight conception of the enormous number of bacteria of various kinds which are brought into the river with the sewage may, perhaps, be gained, if we remember that Sucksdorff[13] found, by a long series of experiments on healthy men with an ordinary mixed diet, that in an average from fifteen days' experiments the number of bacteria discharged daily from the body was more than fifty-three billion. Albany, it will be remembered, has a population of ninety thousand persons.

Rosenberg[14] found that the effect of the sewage of the city of Würzburg, on the River Main, so far as the number of bacteria is concerned, was to increase the number of living bacteria more than twenty times.

But if one should require more proof of the filthy condition of the Hudson just below Albany, he has only to stand on some summer or autumn day, when the tide is at the ebb, on the shores of the Albany Basin, a walled enclosure containing some thirty acres made for the purpose of increasing the city dockage, and into which fifteen sewers empty, carrying the waste of over thirty thousand people. Under these circumstances the observer will certainly be rewarded with both ocular and olfactory evidence of a most convincing nature.

Still, a certain proportion of New Yorkers have gone on amiably consuming their distant neighbors' filth under the impression, when it was thought of at all, that water purifies itself from its contaminations in freezing. That

it does so, so far as its most important ingredients, the bacteria, are concerned, in but a partial degree the investigations above recorded and those about to be set down abundantly show.

And yet, within sight of the walls of the Albany Basin, down the stream, stands one of the houses, with its sewage-laden ice-field, in which this delectable harvest is stored for the comfort of a considerable number of New Yorkers. It was from this region that the ice which was actually being distributed in an outlying district of this city was taken, which, as will be seen below, contained from twenty thousand to fifty thousand living bacteria to one cubic centimetre—that is, to about one-third of a teaspoonful. It is interesting to note that arrangements are made for storage at this point of about twenty-five thousand tons of this ice, and some of it is beautifully transparent.

The first large house stands about four miles below Albany, and below this, in rapidly increasing numbers and capacity, the ice-houses are scattered along the river, always in the vicinity of the water on which their ice is cut. It is only justice to the reputable ice-harvesters and dealers to say that, so far as the writer is aware, they entirely condemn the practice of ice-harvesting in the immediate vicinity of Albany.

If we make an approximate estimate of the amounts of ice for which storage-capacity exists within six-mile reaches below Albany, we find that within the first six miles there is cut and stored in favorable seasons at least 215,000 tons; within the second six miles, 519,000 tons; within the third 328,000 tons; within the fourth, 382,000 tons; within the fifth, 438,000 tons; within the sixth, 71,000 tons; within the seventh, 254,000 tons; within the eighth, 318,000 tons; within the ninth, 198,000 tons; within the tenth, 95,000 tons. That is, about two-thirds of the ice is cut within thirty miles of Albany, and nearly one-fourth is cut within twelve miles.

Spontaneous Purification of the Hudson River Water.—A good deal has been said, and some of it in a very indefinite way, about the capacity of rapidly flowing streams to purify themselves from sewage contamination, particularly if the quantity of freshly added pure water is large in proportion to the amount of contamination, and there is no doubt whatsoever that a great deal is thus accomplished if the conditions be favorable. But it should be borne in mind that the experience which has been gathered during many years of painstaking investigation on the subject of water impurities and spontaneous purification by oxidation, etc., has been largely based on the results of chemical analysis and the deductions

for the most part drawn from it alone. The ammonia and the nitrates and nitrites, which, to the chemical analyst are the exponents of the water's impurities, are simply the products engendered by the life-processes of bacteria, which are, in the majority of cases, themselves present, though undetected in the water analyzed. Now, nothing is more definitely established than that water can and does free itself under favoring conditions, such as exposure to air in running streams, etc., from these organic impurities. That the same conditions destroy the bacteria, which are, after all, so far as we know, the more important active agents in the diseases produced by bad water, has not yet been demonstrated in a sufficiently comprehensive way.

But the conditions in the upper Hudson are peculiar. A river of considerable size, receiving a rather dirty tributary in the Mohawk, reaches Albany contaminated with sewage from Troy. To this comes the sewage of Albany with its ninety thousand souls. That this river, large as it is, must be filthy here would seem hardly to need the demonstrations of science to make clear. In its first twelve miles below Albany it flows through a great, long, narrow archipelago, lies more or less stagnant behind the islands and dikes, and is met, the sewage still pouring in above, and its current reversed by each incoming tide. Below New Baltimore the river channel is more open, but the retarding influence of the tides is still more marked.

Moreover, the sewer-laden water of the upper Hudson, as soon as the ice commences to form, is covered above from contact with the air, and is virtually in the condition of a great closed conduit.

On the other hand, it should not be forgotten that in the comparatively still water behind the islands and dikes there is given tolerable facility for sedimentation of the bacteria, by which means, as experiment shows, a considerable proportion of bacteria may be removed from the upper strata of the water.

The marked effect of the subsiding reservoirs in use in England and elsewhere in freeing the water from various impurities is noteworthy here. Numerous experiments have shown that when water containing bacteria is placed in vessels which are kept quite still the bacteria may settle toward the bottom so completely as to free the upper strata even to the extent of over ninety per cent.[1]

It is these latter considerations which warn us against an unqualified condemnation of the Hudson River water for ice purposes, since only a careful series of experiments can show at what distance below the source of pollution the water may have so far freed itself from bacteria, if it do so to any considerable degree, as to render

it fit for ice-harvesting purposes. In the mean time we must have recourse to biological analysis of the ice itself and see to what extent bacterial contaminations actually exist in the ice harvested in various parts of the river.*

Natural Ice Examined—Sources, Appearance, Mode of Formation, etc.—It was necessary for the purposes which the writer had in view in the prosecution of these studies to know with certainty exactly where the sample of ice to be examined came from, and it became evident at the very commencement of the work that to obtain samples from the wagons which deliver ice through the streets would lead to very uncertain results. These ice-wagons are mostly loaded either from barges on the water-front or from the cars, or from platforms at these places.

Each day's supply may come from more than one source, and these may be entirely unknown to the drivers, who are, moreover, apt to be somewhat reticent as to the exact source of their ice, and not infrequently positively deceptive in the accounts which they give of its origin, at least to the inquiring scientist. The names on the wagons are, furthermore, not altogether to be relied upon, as a rule, as indicative of the exact source of supply, since there is a good deal of speculation in ice and exchange of proprietorship before the product comes to the market. Then, too, a not inconsiderable degree of fancy is exercised in the choice of the name which, in some cases in large letters on the sides of the ice-wagons, would naturally indicate to the consumer the source of his supply, but is, in fact, in many cases entirely misleading. For these reasons the ice for the present studies was in all cases obtained either directly from the barges or canal-boats or cars, the exact source of whose cargoes could be accurately ascertained, or from certain houses the origin of whose ice was known by the writer, or was obtained on the spot of its harvesting by the writer or his emissaries.

Let us now see what the biological analysis of our New York ice shows. I have made over 270 complete analyses of samples taken from different blocks of ice at different times, so as to insure a fair sampling of the product. These specimens were mostly from 1886 ice, but a considerable number were from the 1887 harvest.

* The writer has been particular in obtaining the facts about the Hudson River and other sources of ice-supply here described at first hand whenever this was possible, and for this purpose has seen, and in most cases carefully inspected, nearly all the important ice-houses and ice-fields on the river and lakes and ponds from which New York ice is derived. He wishes to express his indebtedness for many interesting facts about the Hudson River, its currents, dikes, shoals, etc., to Captain Jacob Schermerhorn, who for many years has buoyed the channels in the river in the Government service, and who accompanied him in the inspection of a portion of the upper Hudson.

Their sources were as follows: 153 from the Hudson River, at various points from West Park to the vicinity of Troy, embracing samples from all the more prominent fields and many of the smaller ones; 22 from Rockland Lake; 23 from Swartout Pond; 51 from ice-pond, so-called "Croton Lake;" 5 from Maine; 6 from Verplank's Point; 8 from Tuckahoe; 9 from Van Cortland. Besides these were a number of other samples from these and various other sources, examined for special purposes and not tabulated here.

Now, taking the results of all these analyses of ice from the various sources, we find that the average number of living bacteria contained in one cubic centimetre of the melted ice is 2,033. Or, to express the estimate in more common terms, an ordinary drinking-glass containing half a pint of the melted average ice would harbor about half a million living bacteria of various kinds. He who, impressed with the importance of a pure drinking-water, should perfectly filter half a glass of average winter Croton water, and then add to it an equal quantity of the average ice, would have the satisfaction of replacing the bacteria removed with more than eight times as many from much more uncertain and questionable sources.

But a simple statement of these aggregate numbers, true though they be, gives a very imperfect and, it may be added, a very misleading conception of the real significance of affairs. Such general statements are misleading, if made without further qualification: First, because they do not indicate what proportion, if any, of the bacteria are probably harmful; second, because ice from various sources may contain differing quantities of bacteria; and, finally, because, as will presently be shown, the different parts of the blocks of ice as they come to the market may present very great and important differences in the number of bacteria which they contain. We have, therefore, to examine more in detail the result of the ice-analyses, and we will look first at the distribution of the bacteria in the blocks of ice.

Snow-ice and transparent ice.—If we look at the blocks of ice as it is being distributed from the wagons, we find a considerable variety in their appearance. In some cases the blocks will be clear and transparent throughout. This is most apt to be the case with river ice, while lake and pond ice is more apt to be somewhat whitish in appearance from the distribution through it of larger and smaller air-bubbles. This is, however, by no means always the case.

Again, the ice-blocks may be, for the most part, either transparent or slightly bubbly, while on one side—that side which was uppermost as the ice was forming—there

will be a layer, of from one-half to three inches thick, which is white and opaque and more or less friable. Its opacity is not at all due to any impurities which it contains, but to the fact that it is thickly crowded with air-bubbles, around which the ice is irregularly crystallized. This is called "snow-ice," partly, doubtless, on account of its appearance, and partly because of its mode of origin.

Mode of formation of snow-ice.—After the first film of ice is formed at the surface of the water, the process of freezing goes on downward, as the heat from the water below radiates off into the colder air above. If anything occurs to prevent this radiation of heat upward, the formation of ice ceases. This happens, of course, if the temperature of the air rises above the freezing-point, but it also occurs if any considerable amount of snow collects upon the surface of the ice already formed. The air, which is caught in innumerable tiny cavities between the snowflakes as they settle upon the ice, acts as a blanket to prevent radiation, and thus the formation of fresh ice below comes to a stand-still, even though the weather be quite cold. Snow is for this reason a great bugbear to the ice-harvesters. It must be gotten rid of at any cost, for, if not, the crop stops growing. Now two courses are open to the ice-farmer: If the already formed ice is thick enough to bear he can go on with his horses and scrape the snow off from his ice-field, and this, as the writer is informed, is usually the preferable course when it is practicable and there is promise of plenty of cold weather, because if he gets rid of the snow he may get ice which is clear and transparent throughout, and which, at least for household and drinking purposes, is most popular and valuable.

But if, when the snow comes, the already formed ice is not thick enough to bear, or if the weather prospects indicate a lack of cold, so that he fears lest the ice may not be thick enough for profitable handling, he cuts a series of small holes in various places over his ice-field, the water from below pours up over the surface, merges with the snow and freezes. In this way, while the non-conductibility of the snow-blanket is largely reduced, he gets an additional layer of ice on top. This operation is called "flooding" or "bleeding" the ice. But this partially melted snow-layer is never transparent, because a large number of air-bubbles will still remain entangled in it. This is one way in which snow-ice is formed, on the top of the blocks as we see them in the market, and it is white on account of the large number of entangled air-bubbles.

Very frequently the snow is followed by rain, and then a snow-ice layer may form on top by natural means, from

the water which falls directly upon the ice or runs onto from the banks.

If the ice is thick enough, so that the harvester can afford to do it, this top snow-layer may be planed off, though at considerable expense, leaving transparent ice. But it is the practice of most harvesters to leave a layer of from one to three inches in thickness of the snow-ice on the top of the block, because it forms, on account of its enclosed air-bubbles, a protective layer on one side which retards melting and waste of the clear ice both in the storage houses and in transportation.

It is a frequent practice of some of the more responsible dealers to chip off most of this snow-ice layer before it is weighed out to customers. The temptation to not remove this snow-layer, but to weigh and deliver it with the rest is, however, so great, particularly in years when the supply is short, that it is very often not successfully resisted, as anyone may convince himself who will take the trouble to notice the blocks of ice which are left at houses through the city. Ice having a large amount of snow-ice in the block is known in the slang of the handlers as "fat" ice.

Sometimes when forming both the ice and snow sink a little, and a considerable depth of water covers both and freezes; then the snow-ice will be embedded in the block in the form of a dense, bubbly streak between layers of transparent ice.

Bubbly streaks in ice.—Still again, one frequently sees strata of air-bubbles enclosed in the block of ice, which lie parallel to the surface but below the snow-layer in the transparent ice which was formed downward. These are apparently due to the accumulations beneath the ice of air-bubbles which have freed themselves from the water as it freezes, or, in ponds, in part at least, from decomposing matter at the bottom, and finally became enclosed as congelation proceeded downward. These streaks or bands of enclosed bubbles which lie between bands of clear ice may be narrow or broad, and a series of them may often be seen lying close together with clear ice-bands between them, like the strata of sedimentary rock.

These alternating bands of bubbly and transparent ice give us a very interesting record of the varying temperature during the time in which the ice was forming. For it appears that if the temperature is low for a considerable period, so that the formation of ice downward in the water steadily proceeds, this ice, particularly in rivers or where the water is in motion, will be apt to be quite transparent, containing but a few scattered bubbles. If, however, the temperature rises, so that the ice does not form at all or makes but slowly, bubbles are apt to col-

lect on the under surface and become enclosed in streaks when ice begins again to form. Thus we may have a series of narrow, closely packed, alternating, transparent, and bubbly layers, as a record of the nightly freezing and the daily thaw, or a series of broader bands when the changes of temperature follow one another less closely.

Disintegration of ice.—Finally, ice which has been exposed to a moderately warm temperature out of doors is apt to undergo a gradual molecular disintegration, and long air-bubbles may appear in it along the sides of the ice-crystals of which, though invisible, the solid ice is composed. As these ice-crystals, after the first surface film is formed at the commencement of the freezing, lie with their long axes perpendicular to the free surfaces of the ice, the long bubbles caused by disintegration lie in the same direction.

This process of disintegration is called "combing," and large masses of ice may in this way become very rotten and friable, while retaining their external form, either with or without the collection of long air-bubbles between the partially melted ice-crystals. With air which enters the ice in this way by its disintegration, and with vacuoles which look like air-bubbles, but are caused by the localized melting of small portions of ice within the solid block, the present study has nothing to do. For a long series of analyses of ice in this condition, made by the writer, shows, as was to be expected, that the presence of these disintegration air-bubbles and of vacuoles has no relation whatsoever to the number of bacteria present in the ice.

Lake and river ice.—Exactly why pond and lake ice should be apt to contain more scattered air-bubbles than river ice, and hence to appear more or less whitish, is not altogether clear, nor is it by any means always the case. But the tendency seems in a measure due to the absence of running currents of water, which in rivers would tend to carry off the air-bubbles, while in still ponds and lakes these would be more apt to be caught and frozen where they lodged beneath the ice.*

Sometimes large volumes or "blebs" of air or gas are seen beneath the ice of ponds. The contents of these blebs are, in some cases at least, inflammable, as has been seen by making a small hole in the ice above them and applying a match as the gas is forced up. This gas, of course, and doubtless a considerable proportion of the smaller bubbles, in some cases, is the result of vegetable decomposition at the bottom of the water, a process which, as is well known, is sometimes in summer very active.

* Many interesting facts about ice formation and characters may be found the files of the very readable Ice Trade Journal, published in Philadelphia.

Popular prejudice against bubbly ice.—The popular prejudice against white—that is, bubbly—ice, which is very strong and, so far as we have hitherto known, as unreasonable as it is potent, is apt to work against some of the very best sources of ice-supply, namely, ponds and small lakes. "Clear ice," say the observant consumers, "we can look right through and see for ourselves that there is nothing bad in it. We can't see through white ice, and there must, therefore, be something in it, and we don't want ice which is so full of something or other that we can't see through it." It is in vain that the laws of optics are called to the help of the ice-dealer; in vain that the "something" is again and again demonstrated to be nothing more harmful than air; in vain that purity and whiteness in snow are shown to be compatible qualities. One consumer trusts his own senses rather than the refinements of science; another, perhaps at last convinced, still urges that the market value of winter wind or decomposition-gas is not rated at ten dollars per ton.

It was primarily in view of this condition of affairs that throughout the following series of ice-analyses the writer carefully separated the samples of ice subjected to examination into two classes: First, clear ice, or ice which contained but a few scattered bubbles; and, second, snow-ice and very bubbly streaks formed beneath the surface.

This distinction between the snow and bubbly and the transparent ice, which was made by the writer at first with a view of combating the popular prejudice against white ice, proves, after all, to be an exceedingly important factor in forming our opinion of the quality of a given ice-sample.

The first thing which strikes the observer, as he examines in detail the results of the analyses of the ice of both these classes, is the great variability in the number of living bacteria which ice, even from different parts of the same block, contains. This it is which makes a large number of analyses imperative, if we would arrive at general conclusions regarding the number of bacteria which ice from any given source contains. This unequal distribution of the bacteria in ice is not surprising, since the same inequality has been repeatedly shown to exist in water, owing doubtless to minute currents and eddies and incomplete mixing or distribution of the contaminating material.

Results of Analyses of Hudson River Ice.—Let us look first at the Hudson River ice, and for convenience we will make separate tables for the ice which is harvested immediately below Albany and that which is gathered in the region from six to fifty miles below.

TABLE XIII.—*Number of Living Bacteria in One Cubic Centimetre of Melted Ice from Various Points on the Hudson River, from Castleton, about Six Miles below Albany, to Rhinebeck, about Fifty Miles below.*

Transparent ice, 83 samples.		Snow-ice and very bubbly streaks, 34 samples.	
Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.	Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.
Less than 10........	In 23 samples.	Less than [illegible]........	In 0 sample.
Bet. 10 and 50....	“ 22 “	Bet. 100 and 200..	“ 1 sample.
“ 50 “ 100....	“ 1[illegible] “	“ [illegible] “ 300..	“ 2 samples.
“ [illegible] “ 200....	“ 1[illegible] “	“ [illegible] “ 500..	“ 1 sample.
“ 200 “ 500...	“ 4 “	“ [illegible] “ 1,000..	“ 5 samples.
“ [illegible] “ 1,000....	“ 3 “	“ 1,[illegible] “ 2,000..	“ 4 “
“ 1,000 “ 5,000....	“ [illegible] “	“ 2,000 “ 5,000..	“ 1[illegible] “
“ [illegible] “ 6,000....	“ 1 sample.	“ 5,000 “ 10,000..	“ 7 “
		“ 11,[illegible] “ 12,000..	“ 2 “

In two cases only were samples found which contained in one cubic centimetre no bacteria at all.

TABLE XIV.—*Number of Living Bacteria in One Cubic Centimetre of Melted Ice from the Hudson River just below Albany.*

Transparent ice, 24 samples.		Snow-ice and very bubbly streaks, 12 samples.	
Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.	Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.
Less than 50...........	In 3 samples.	Less than 100	In 0 sample.
Bet. 50 and 100....	“ 3 “	Bet. 100 and 200 .	“ [illegible] “
“ 100 “ 200 ...	“ 5 “	“ [illegible] “ 300..	“ [illegible] “
“ 200 “ 500....	“ 3 “	“ 3[illegible] “ 500..	“ 0 “
“ 500 “ 1,000 ..	“ 3 “	“ 500 “ 1,000..	“ [illegible] “
“ 1,000 “ 5,000...	“ 6 “	“ 1,[illegible] “ 5,000..	“ [illegible] “
“ 5,000 “ 6,000....	“ 1 sample.	“ 5,000 “ 10,000..	“ 1 sample.
		“ [illegible] “ 20,000..	“ 4 samples.
		“ 20,000 “ 30,000..	“ 4 “
		“ 30,000 “ 40,000..	“ 1 sample.
		“ 4[illegible] “ 50,000..	“ 1 “
		55,000..	“ 1 “

It should be remembered that all of the analyses recorded here were made from specimens taken from different cakes of ice, and so far as possible from those cut in different places in the field. So that a fair sampling was insured.

The following table summarizes these results, giving the averages of the detailed analyses :

TABLE XV.—*Hudson River Ice.*

Source.	Number of samples.	Forms of ice.	Number of bacteria in 1 c.c.
All sources...............	153	Trans. & snow.	3,[illegible]
All sources...........	107	Transparent...	398
	46	Snow.........	9,187
From 6 to 50 miles below Albany........	83	Transparent...	189
	34	Snow.........	3,693

While the great difference in the bacterial content of ice taken from the region of Albany and that gathered farther down the stream is thus very evident, a still more graphic representation is afforded if we take the average numbers of living bacteria found in one cubic centimetre of both transparent and snow ice gathered at various points along the Hudson River and express them in a chart.

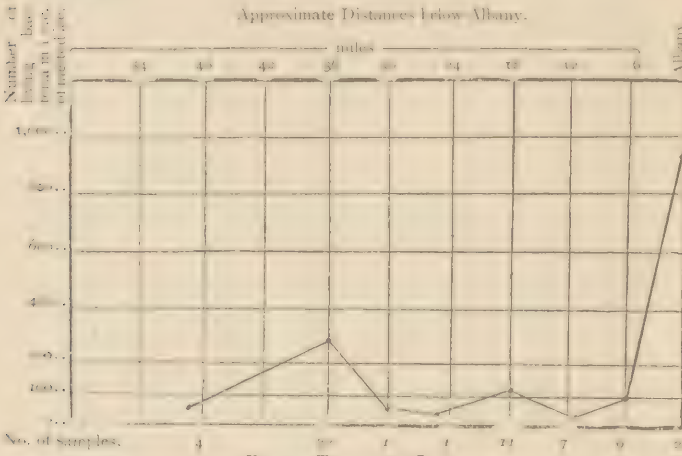

FIG. 1.—Transparent Ice.

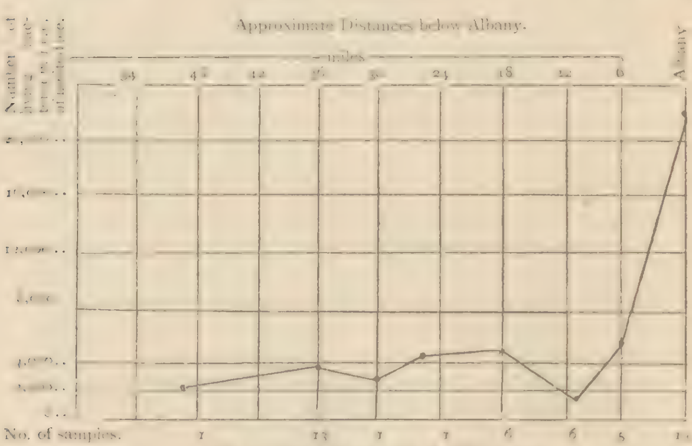

FIG. 2.—Snow Ice and very Bubbly Streaks.

These charts show with great distinctness that ice formed near Albany contains vastly greater numbers of bacteria than that formed at some distance below. It is evident, therefore, that by natural agencies the water of the river is freed to a certain degree from bacteria after running for some distance. Still, the average num-

ber of bacteria left in the ice is considerably above that which can be regarded as wholly safe.

It should be said, in justice to the Hudson River ice, that the crop of the winter 1885–86, from which most of the analyses above recorded were made, was of poorer quality than usual, because the season was an unfavorable one; but the careful selection by the writer of well-formed samples for analyses would partly, at least, offset the general unfavorable conditions.

So far as this series of analyses shows, the ice does not, as one might at first expect, get freer and freer from bacteria as the distance from Albany increases, but from six to fifty miles below Albany, with local fluctuations difficult to explain, remains very nearly the same. It, of course, presents some variation when cut below the smaller towns which drain into the river.

But a very much more extended series of examinations will be necessary before we can determine with any great degree of accuracy how far the river has to run below a source of sewage contamination in order that the water may, by freezing and other natural agencies, free itself to a proper degree from its bacterial contaminations, or if, indeed, it does so at all.

The remarkable difference in the bacterial contents of snow ice together with very bubbly streaks, and transparent ice, prevails in all parts of the river alike, and it is surprising, not only how constant the difference is, but also how abrupt the transition is in the ice-block between the few and the many bacteria, corresponding exactly to the line of demarcation of the clear and bubble ice. Thus in a series of examinations, made from snow ice or very bubbly streaks and very clear ice in the same ice-cake in various samples from the Hudson, we get results expressed in the following table:

TABLE XVI.—*Relative Number of Living Bacteria in 1 c.c. Transparent Ice and Snow Ice taken from the Hudson River, as shown by the Analysis of Adjacent Portions of the same Ice-blocks—Specimens from Various Parts of the River.*

Source.	Greenbush, near Albany.	Castleton.	Barren Island.	Coxsackie.	Germantown.
1 Transparent..	46	66	32	44	150
Snow	10,020	5,184	520	12,642	9,234
2 Transparent..	3,192	92	122	92	919
Snow	15,624	2,430	268	430	11,584
3 Transparent..	[illegible]	585	......	676	[illegible]
Snow	55,062	9,600	......	4,294	114
4 Transparent..	218	......	......	......	2
Snow	9,690	......	......	......	1,308
5 Transparent..	918	......	......	......	......
Bubbly streak	26,049	.. ..	......	......	......

These are only a part of the analyses made in this way, and are taken quite at random from the list. In no case was there an exception to the rule that snow and very bubbly ice contains a much greater number of bacteria than adjacent transparent ice from the same block.

The very bubbly streaks, although containing, as a rule, very many more bacteria than the transparent ice, still do not generally contain nearly as many as the top layers of snow ice.

RESULTS OF ANALYSES OF LAKE AND POND ICE.—Before attempting to explain this curious difference between snow ice and transparent ice, let us look at the results of the analyses of the lake and pond ice from the above-described sources.

TABLE XVII.—*The Number of Bacteria in Rockland Lake Ice.*

Transparent ice, 17 samples.		Snow ice, 5 samples.	
Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.	Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.
Less than 10........	In 1 sample.	Less than 100......	In 0 samples.
Bet. 10 and 50..	" 4 samples.	Bet. 100 and 200	" 0 "
" 50 " 100..	" 3 "	" 200 " 300	" 0 "
" 100 " 200..	" 5 "	" 300 " 500	" 0 "
" 200 " 500..	" 2 "	" 500 " 1,000	" 0 "
" 500 " 1,000..	" 2 "	" 1,000 " 2,000	" 3 "
		" 7,000 " 10,000	" 2 "

TABLE XVIII.—*The Number of Bacteria in Ice Pond Ice.*

Transparent ice, 36 samples.		Snow ice, 15 samples.	
Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.	Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.
Less than 10........	In 9 samples.	Less than 100.....	In 1 sample
Bet. 10 and 50.	" 1 "	Bet. 100 and 200.	" 1 "
" 50 " 100.	" 6 "	" 200 " 300.	" 0 "
" 100 " 200.	" 4 "	" 300 " 500.	" 1 "
" 200 " 500.	" 6 "	" 500 " 1,000.	" 3 samples.
" 500 " 1,000.	" 3 "	" 1,000 " 2,000.	" 2 "
" 1,000 " 2,000.	" 4 "	" 2,000 " 5,000.	" 4 "
" 3,000 " 4,500.	" 3 "	" 5,000 " 6,300.	" 3 "

TABLE XIX.—*The Number of Bacteria in Swartout Pond Ice.*

Transparent ice, 16 samples.		Snow ice, 7 samples.	
Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.	Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.
Less than 10.......	In 13 samples.	Less than 100......	In 2 samples.
Bet. 10 and 50...	" 1 sample.	Bet. 100 and 200.	" 0 "
" 50 " 100...	" 1 "	" 200 " 300.	" 1 "
" 100 " 200..	" 0 "	" 300 " 500.	" 2 "
" 200 " 300...	" 1 "	" 500 " 1,000.	" 1 "
		" 1,000 " 2,000.	" 1 "

A smaller number of analyses was made from Tuckahoe, Van Cortland, and Verplank's Point ice, but the tables are given for the sake of comparison.

TABLE XX.—*Number of Bacteria in Tuckahoe, Van Cortland, and Verplank's Point Ice.*

TUCKAHOE.

Transparent ice, 4 samples.		Snow ice, 4 samples.	
Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.	Number of living bacteria in 1 c.c. of the melted ice.	Number of samples.
Less than 10........	In 3 samples.	Less than 100.......	In 4 samples.
Bet. 10 and 50......	" 1 sample.		

VAN CORTLAND.

Transparent ice, 5 samples.		Snow ice, 4 samples.	
Less than 10........	In 3 samples.	Less than 100.......	In 3 samples.
Bet. 10 and 50......	" 2 "	Bet. 100 and 200....	" 1 sample.

VERPLANK'S POINT.

Transparent ice, 3 samples.		Snow ice, 3 samples.	
Less than 10........	In 3 samples.	Less than 10........	In 3 samples.

It will be seen from the last table that while the specimens from Van Cortland and Tuckahoe were taken from different blocks and thus more fairly represent the ice, the samples in the case of Verplank's Point were all from a single block, taken from the pond as a sample before the ice-cutting season of 1886–87 began. But as it was only a single specimen, the value of the result is but moderate.

The same sharp contrast in the number of bacteria in transparent ice and snow ice, or very bubbly streaks, is found in lake and pond ice which we have seen in river ice, as may be seen by the following table :

TABLE XXI.—*Relative Number of Living Bacteria in 1 c.c. Transparent and Snow Ice from the Same Cakes —Specimens from Lakes and Ponds.*

Source.	Rockland Lake.	Swartout Pond.	Ice Pond.	Tuckahoe and Van Cortland.
Transparent	67	1	10	2
Snow	1,578	95	236	64
Transparent	190	214	[illegible]	24
Snow	1,260	367	5,520	54
Transparent	115	....	56	....
Bubbly streak	9,120	....	306	....
Transparent	14	....	....	....
Bubbly streak	1,368	...	....	....
Transparent	....	...	22	40
Snow	....	....	3,960	170

It will be seen from this table and the similar one constructed from analyses of the river ice, that the number of bacteria in the transparent ice affords no criterion of the number in the adjacent snow ice, and *vice versa.* So that in a cake of ice whose snow-layer contains an unusually small number of bacteria—as snow ice goes—the transparent ice may, on the other hand, contain an unusually large number ; and the converse is equally true. Taking all the analyses of the lake and pond ice together, there is a much larger number of samples containing no bacteria at all than in the Hudson River ice. This absolute freedom is in both cases always in transparent ice. Thus, in 16 specimens from Swartout Pond there were 4 in which one cubic centimetre of the ice was entirely free from bacteria. In 118 samples of lake and pond ice there were 8 containing no bacteria, while in 153 samples of Hudson River ice there were only 2 entirely free, and these were gathered from the lower part of the river.*

TABLE XXII.—*Lake and Pond Ice—Summary.*

Source.	Form of ice.	Number of samples.	Number of bacteria in 1 c.c.
Rockland Lake	Transparent....	17	181
	Snow	5	4,116
Swartout Pond	Transparent....	16	20
	Snow	7	565
Ice Pond	Transparent....	36	618
	Snow	15	2,469
Tuckahoe Pond	Transparent....	14	6
	Snow	4	[illegible]
Van Cortland Lake....	Transparent....	5	16
	Snow	4	81
Verplank's Point.......	Transparent....	3	5
	Snow	3	1

* *Maine Ice.*—A few samples of Maine ice from Gardner's Bay were examined. The average number (in one cubic centimetre) in transparent ice was 85 ; in snow

The exception to the rule that snow ice contains more bacteria than the adjacent transparent ice, which is seen in the result from a single cake from Verplank's Point, will be considered below.

If, for the sake of comparing the lake and pond with the Hudson River ice, we place the averages together, we have the following table :

TABLE XXIII.—*Relative Number of Bacteria in One Cubic Centimetre of Hudson River Ice and Lake and Pond Ice.*

Form of ice.	Hudson River, 153 samples.	Lakes and Ponds, 119 samples.
Transparent	389	318
Snow	9,187	1,636

If, however, in order to give the Hudson River ice its due credit we exclude the ice cut near Albany, we have the following table :

TABLE XXIV.—*Relative Number of Bacteria in One Cubic Centimetre of Hudson River Ice, from Six to Fifty Miles Below Albany, and Lake and Pond Ice.*

Form of ice.	Hudson River, 117 samples.	Lakes and Ponds, 119 samples.
Transparent	189	[illegible]
Snow	3,693	1,636

The summary of the last two tables is at first sight rather surprising, for we see that the average number of bacteria in a cubic centimetre of transparent ice from the lakes and ponds, free as they are from obvious sewage pollution, is still almost as great as the average in transparent ice from all parts of the river ; while if we exclude ice from Albany the average number in ice from the remainder of the river is even considerably less than that of the pond and lake ice.

If we look, however, at the transparent ice from the various lakes and ponds, we see that the general average is raised by the ice from Ice Pond, in which 618 represents the average, as against 78 which represents the average of all the other ponds and lakes taken together.

ice, 250. One block showed in the top snow-layer in one cubic centimetre, 378 ; the middle of the thick transparent portion below gave 198 ; while the lower part of the transparent ice—*i.e.*, that which was formed last—contained only 37. The number of specimens examined was, however, so small—five—that inferences as to the bacterial qualities of the Maine ice should not be drawn from the results.

Now the Ice Pond ice, in the samples examined, was especially rich in the fluorescent bacillus, which, as experiments show, proliferates readily in water—even in boiled distilled water in the laboratory experiments. This fact, together with the partially stagnant character of the pond, with its large communicating swamp, would seem to fully explain the high average which is found here, especially when we remember how resistant is this species to the cold.

TABLE XXV.—*Showing Average Number of Bacteria in One Cubic Centimetre of Melted Ice from Various Sources as Compared with the Average Number in Croton Water during the Winter of* 1886–87, *when both were Examined.*

	Average number of bacteria in 1 c.c. of the melted ice.	Average number of bacteria in 1 c.c. of Croton water, winter 1886–87, 32 samples.
Transparent and snow ice and ice with very bubbly streaks, from all sources; 272 samples	2,033	243
Transparent and snow ice and ice with very bubbly streaks, from all sources except just below Albany; 236 samples	971	243
Transparent or slightly bubbly ice from all sources; 188 samples	363	243
Transparent or slightly bubbly ice from all sources except just below Albany; 164 samples	252	243

We see from this table, which summarizes the results of a large number of analyses from many sources, that if the bacteria in ice are of any significance at all, the snow-layer is to be avoided for drinking purposes, and also that the sewage of a large town makes a good deal of difference in the bacterial content of the ice gathered near it.

We are further led to the rather striking conclusion that if we use only transparent ice and avoid that which is harvested near Albany, sewage-polluted as the Hudson River is, we do not on the average get more bacteria than in our ordinary unfiltered winter Croton water. The significant difference in the *species* of bacteria in the two cases will be considered farther on.

Although the very bubbly streaks contain, as a rule, many more bacteria than the transparent ice adjacent to them, the proportion in real snow ice is almost always so much greater, that it alone appears to be of great importance in this respect. Indeed, the rule that very bubbly

and snow ice contains more bacteria than transparent ice holds good only when the water from which the ice is formed contains a considerable number of bacteria. Thus, the only exception to the rule which has been encountered by the writer in this long series of examinations was in ice from Verplank's Point, in which, as will be seen from Table XX., the snow-layer contained a less average number of bacteria to one cubic centimetre than the transparent ice, and the number in both was very low. But the water from this pond, which was collected at the time the ice was secured, contained in an average of four analyses only 175 living bacteria.

Bacteria in slightly Bubbly Ice.—A long series of analyses made for this purpose have shown that this relationship between the number of air-bubbles and the bacteria in ice exists to an appreciable extent only when the air-bubbles are very numerous, as in real snow ice and in very bubbly streaks; while moderately bubbly lake ice, which has small bubbles scattered through it, so as to look whitish and opaque only in large blocks, does not show an appreciably larger number of bacteria than quite transparent ice from the same source. This will not seem strange if we examine carefully typical moderately bubbly lake ice, which looks quite opaque in large cakes; for we then find that in small pieces it is almost as transparent as the clearest ice, and that the number of scattered bubbles required to give a large block of ice an opaque whitish appearance is really very moderate indeed.

We thus see that the unreasonable popular prejudice against bubbly ice appears to have, after all, a real basis, so far as the snow-ice layers so frequent on the top of the ice-cakes are concerned; the ordinary opaque ice, however, with comparatively few bubbles, is apparently just as free from bacteria as the most transparent.

Such moderately bubbly lake ice, or ice from any source containing scattered bubbles, may on exposure become very much whiter; and very scantily bubbly streaks or bands in transparent ice may become, under the same conditions, so white and broad that, when viewed at a little distance in the block, they look like layers of sunken snow ice. But a close inspection in either case shows that this change is due to an internal disintegration of the ice around the air-bubbles by heat transmitted through the surrounding intact ice. In this way, as a little of the ice along the sides of the invisible crystals melts, and in so doing occupies less space than before, the air in the original bubbles expands to fill the vacuum, and the rarefied bubble becomes elongated to fill the long space between the crystals.

In this way a given plane of the ice-block, which formerly contained so few scattered rounded bubbles that they were almost invisible, or at least quite inconspicuous, may in a short time become the seat of a broad, palisade-like stripe. The insignificance of these long disintegration bubbles has been emphasized above. If a fragment of ice containing these rarefied bubbles, which are embedded in solid ice and not in communication with the external air, be put under water in a shallow glass dish and carefully watched as it melts, these disintegration bubbles may be seen to suddenly contract as they are freed by the melting of the ice around them and rise to the surface.

Reasons for Excess of Bacteria in Snow Ice and in very Bubbly Streaks.—Let us now see if this marked excess of living bacteria in snow ice and in very bubbly streaks over the solid transparent ice can be explained.

It was noticed by the writer, in the large number of analyses made of snow ice and also of the very bubbly streaks in clear ice, that two or three species of bacteria were almost always particularly abundant. The most common of these was the fluorescent bacillus above described. The other most common form is a short bacillus forming spreading iridescent colonies, not fluidifying.

Both of these bacilli are capable of performing vigorous movements in water, as may be readily seen under the microscope. Both of them grow much more abundantly on the surface of the gelatin where there is plenty of air, and if the air be cut off, as by laying a mica-plate on the surface of the gelatin where they are planted, their growth is very meagre. They are what are called aërobic forms of bacteria.

In view of this character, it seemed not improbable that these species, and perhaps others as well, would tend to make their way in the water toward the air-bubbles which might be collected at any point, and be caught here by the freezing of the water. If this were true, it would explain, in part at least, the curious fact of the excess of bacteria in bubbly layers of ice over the clear portions near by.

In order to test this hypothesis the following experiments were devised and executed. Three deep, flat dishes were carefully sterilized and filled about two-thirds full of sterilized water, in which had been thoroughly diffused some of the above-described fluorescent bacilli. It was found by an analysis of this mixture that one cubic centimetre of the water contained 21,384 living bacteria. Now I had gathered for this purpose, in a large clean flask on the morning on which these experiments were

got under way, a quantity of clear, freshly fallen snow. This snow was obtained in the upper part of Central Park, at a point as far away as possible from paths and roads, which were in a very clean condition, however, as they were just being cleared after the snow-fall. Analysis of the water obtained in melting this snow showed that it contained on the average only four bacteria to the cubic centimetre, a number so small as to be of no importance in this connection.

Now three small wads of this snow were made by tamping it firm with a clean knife-blade, and these were completely soaked with sterilized water. They were then dropped into the dishes containing the bacteria in the water, one wad into each. The dishes were then carefully covered, allowed to stand for about ten minutes in a cold place so that the snow would not melt completely in the water, and were then put into the refrigerator, where, within an hour, they were frozen solid.

It was found on examination of the dishes that in the centre of each lay the lump of snow, a little smaller, but otherwise not apparently changed, and enclosing many air-bubbles. From this snow-lump a large number of elongated air-bubbles radiated in all directions, while around the edges of the dishes was a zone of perfectly transparent ice. We thus have an almost exact experimental reproduction of the conditions found in adjacent strata of snow or bubbly and transparent ice. The ice in these dishes was examined, one at the end of four days, one on the seventh, and the third on the fourteenth day.

At the examination the dishes were set in a vessel of warm water which came up around the sides, and when the transparent zone at the sides and bottom was melted off, the resulting water was drained off after measured quantities for duplicate analyses had been secured by means of sterilized pipettes. The bubbly central portion was then allowed to melt, and duplicate samples of this were examined.

The following figures show the results :

DISH No. 1.	DISH No. 2.	DISH No. 3.
Outer clear zone contains in 1 c.c. 5,366 living bacteria.	Outer clear zone contains in 1 c.c. 1,808 living bacteria.	Outer clear zone contains in 1 c.c. 368 living bacteria.
Central bubbly zone contains in 1 c.c. 6,048 living bacteria.	Central bubbly zone contains in 1 c.c. 3,154 living bacteria.	Central bubbly zone contains in 1 c.c, 798 living bacteria.

It will thus be seen that the bubbly central portion, which when dropped as sodden snow into the bacterial fluid contained practically no bacteria at all, harbored, when examined together with the stratum next outside of it, into which a part of its air had been forced

along the line of crystallization, a considerably larger number of living bacteria than the peripheral zone which contained almost no air-bubbles. This condition of affairs would seem to indicate that the bacteria had worked their way toward the air-bubbles during the short interval which elapsed between the introduction of the bubbles in the snow and the solidification of the mass by freezing.

Still these results could be explained by supposing that in some way the bacteria which lay among the radiating air-bubbles, which had been forced out into the fluid by the freezing, were not killed in as great numbers as in the external transparent zone. We must see whether in fact these bacteria can travel through water toward air-bubbles. To test this several glass slides, with small concavities or pits in their upper surfaces, were sterilized, and the pit or cell nearly completely filled with sterilized water, in which had been uniformly diffused a small number of the fluorescent bacilli. The number was so small that the water in the cell remained perfectly transparent. Now a thin cover-glass was dropped over the cell in such a way as to leave one small bubble of air, the rest of the cell being completely filled with the bacteria-containing water. A rim of oil was now painted around the edge of the cover-glass, so that contact with the external air was completely shut off. Of course in these manipulations great care was taken that no external contamination should occur.

These slides were now set aside in a moderately warm place and examined after a few hours. In every case a distinct cloudy ring, like a halo, was readily seen close around the air-bubble, sometimes most marked at one side, while the remainder of the water in the cell was perfectly clear. An examination with the microscope showed this ring to be composed of large numbers of bacteria of the species originally introduced into the water. These apparently had made their way toward the bubble, close around which they were clustered.

But yet another possibility must be considered, namely, that the cloudy mass of bacteria around the air-bubble may not have come there from the surrounding water, but have found in this place conditions suitable for their proliferation and growth, and so been formed in large numbers on the spot.

Another set of slides was therefore prepared in exactly the same way, but, instead of being left in a warm place, they were put into a jar and sunk in a tub which contained a large quantity of melting ice and water, that is, at a temperature not much above freezing. Examination of these specimens after twenty-four and forty-eigh

hours showed in a most marked manner, the halo of bacteria around the bubble in every case.

Now at this temperature, so far as we know, bacteria do not proliferate, so that it would seem to be true that in some cases at least bubbly ice contains more bacteria than adjacent transparent ice, because certain bacteria, owing to their need of air, tend to collect around air-bubbles which are present in water, and are caught there when freezing occurs.

It is not probable that this is the only reason, or applies in all cases. It is probable that in most cases the top snow-ice layer contains more bacteria because these are washed down upon the surface from the shores of the bodies of water on which the ice is forming, or come from the air.

Pengra has shown, as reported by Gardiner,[8] that in some cases at least the snow ice contains a considerably larger percentage of solid material than the clear ice below.

It is conceivable, also, that the physical conditions of the ice in which air-bubbles are very abundant and the crystallization irregular are such that less numbers of bacteria are killed in the freezing than in the more compact transparent ice.

Englemann,[16] in 1881, observed the tendency of certain bacteria to make their way in fluids to the edges of air-bubbles and to the vicinity of fluids containing oxygen, or plants which were developing it by their life-processes, and suggested this action of such bacteria as a delicate means of detecting the presence of the minutest quantities of oxygen in fluids.

The Different Species of Bacteria present in the Lake, Pond, and River Ice supplied to New York City.—A large number of different species of bacteria have been separated from the ice examined, in the form of pure cultures, and the life history of some of them has been traced in detail. But it is not within the scope of this article to enter into this part of the subject, because the work is not yet completed. No experiments have yet been made with a view of determining whether any of the species isolated are pathogenic.

It should be stated, however, as bearing directly upon our theme, that while the number of different species commonly occurring in the pond and lake ice is moderate, two or three being usually largely in excess, the number of species in the Hudson River ice is very great, more especially so in the ice formed near Albany. This is what would be expected when we remember what enormous numbers of different forms are always to be found in sewage and in sewage-contaminated streams or

other bodies of water. The fluorescent bacillus appears to be more abundant in some of the pond ice, such as that from Ice Pond, than in the river ice.

It is not a little curious that, in the same block of ice, different strata often show a marked difference in the species of bacteria which preponderate. So that we sometimes have in ice, not only, as above mentioned, a record of the temperature and other conditions of the air at the time the ice was forming, but also a memorandum, not less precise than that afforded by the fossils in geologic strata, of the flora which was most predominant in the water when it solidified. We are more fortunate than is the geologist, however, thanks to the method of biological analysis, in that by supplying the proper conditions of environment and nutrition, we can call our bacterial fossils back to life and make out the vital characters which, in their dormant state, are not revealed.

SUMMARY.—Let us now review briefly the more prominent facts which this study has elicited. We have seen that by the biological analysis of water and of ice we are enabled to detect with great certainty the presence of bacteria, some species of which can give rise to serious disease, and that the chemical analysis alone does not suffice, in cases in which such organisms may be present, but that when we have determined the number of bacteria present in water or ice, a great deal of careful study of other conditions is still necessary in order to determine whether the water or ice is suitable for use or not.

We have seen that the popular impression that water purifies itself in freezing is only partly true. While some gross particles, and to a certain extent materials in solution may be largely removed, the bacteria, which are the most important, if not the sole agents in water deleterious to health, are only in part destroyed by the act of freezing. This partial purification from bacteria is not brought about by their expulsion from the water, but by the death of a varying proportion of them, which cannot survive this reduction of temperature. So that, if the bacterial contamination of the water is extreme, or is largely made up of the more hardy species, the ice formed from it, even though quite transparent, may still contain large numbers of the living germs.

Different species of bacteria possess differing degrees of vulnerability to the action of low temperatures. In some species nearly all the individuals are killed by prolonged freezing in water, while in other species a small proportion only is destroyed, and between these extremes are other species possessing intermediate degrees of resisting power.

Certain species of bacteria which are capable of producing serious and even fatal diseases in man—the bacillus of typhoid fever and the common bacterium of suppuration—are capable of resisting a prolonged exposure to a low temperature with the destruction of a part only of the individuals thus exposed.

The capacity of resisting a low temperature varies not only in the different species, but among the individuals of the same species, depending upon their condition of vitality when subjected to the deleterious influence. It varies also with the time of exposure to the cold and its intensity, and repeated freezings and thawings suffice to completely exterminate individuals and species which can successfully resist a steadily maintained low temperature. A persistent low temperature without freezing is more efficacious than when crystallization occurs.

While no absolute percentage of destruction can be given which will indicate the degree to which water containing bacteria usually purifies itself from them in the act of freezing, experimental data justify the belief that in ordinary natural waters there may be a purification of about ninety per cent.

The effect of freezing may in a general way be compared to that of filtration, but there is a very significant difference between them. By filtration the various species, dangerous and harmless, are eliminated with about equal efficiency, while in the purification by freezing the dangerous disease-producing species may be retained if they resist low temperatures, while more or less of the harmless forms may be destroyed. Freezing, therefore, acts as a selective filtration might, and may not free the water from all forms alike.

We have seen that the ice supplied to New York City comes from a series of naturally excellent lakes and ponds and from a great tidal river largely contaminated with sewage in its upper regions, and that by far the larger proportion of the ice comes from the latter source.

It has furthermore been shown that, while the conditions of the upper Hudson do not seem, during the ice-forming season, to be such as would favor purification from organic matter by oxidation, they do seem to be theoretically, and are shown to be practically, favorable to a considerable degree of spontaneous purification from bacteria by sedimentation, but that the limits and extent of this purification are yet to be made out.

Coming to the actual analyses of the ice from both the river and the lakes and ponds, we find a very much greater number of bacteria in the snow ice and in the very bubbly streaks than in the transparent ice, particularly in the snow ice on the top of the cakes. We find

that while a part of this excess may be due to the washing down upon the surface of the ice from the shores of bacterial impurities, or their collection from the air, a not insignificant share is probably due, at least in the bubbly streaks, to the tendency which some forms of bacteria exhibit to collect in the vicinity of air-bubbles, and perhaps also to unknown physical conditions in the irregularly crystallized ice about these bubbles. Regarding the species of bacteria, we find that they are much more varied and abundant in the Hudson River ice than in that of the lakes and ponds, while in both there is a considerable proportion of the relatively harmless water bacteria.

We find that while the number of living bacteria varies greatly, not only in different parts of the same block of ice, but also in ice from different parts of the river and from the different lakes and ponds, the average number is considerably greater in ice from the Hudson River than in that from the lakes and ponds, even when ice taken from immediately below Albany is excluded from the estimate.

We have seen also that the average number of bacteria in ice from all sources taken together is far beyond the general standard which even a moderate degree of purity would allow.

But it is also evident that the transparent ice from some of the lake and pond sources presents in general a most admirable degree of freedom from bacteria.

Interpretation of Results.—We now stand at last face to face with the most difficult and at the same time the most important part of our study, namely, the interpretation of its results and the suggestion of the practical lessons which it teaches.

We must be guided in this task by the general considerations which were set forth at the commencement of this paper, when we were reviewing the practical value of the biological methods of water analysis.

We saw, then, that the simple statement that a given sample of water contained a large number of bacteria was without great significance, unless with it we have an account of the condition of the source of the water at the time of the collection of the sample, because a large proportion of the bacteria ordinarily present in natural waters are, so far as we yet know, relatively or absolutely harmless. We must know whether a considerable proportion of the bacteria present are the at least relatively harmless water bacteria, whether the source may possibly be contaminated with sewage, etc.

Now, exactly the same questions must be asked regarding the sources of our ice.

Considering first the ponds and lakes, we find that the natural situation and surroundings of most of them are excellent and that evident sources of contamination with excretory material can be largely excluded. Whether, in the case of Rockland Lake, the dwellings on the hill-side near it might furnish sources of absolute danger in the event of an outbreak of typhoid fever, or not, the writer is not prepared to say, and would leave this and all other detailed criticism of the sources of ice-supply to those who, having the public health in charge, can speak authoritatively on the matter.

The large number of bacteria present in the average Ice Pond ice may readily be accounted for by the proliferation of water bacteria and by the connection which this sheet of water has with a swamp, and experiment shows that a considerable number of these are actually forms which proliferate in water and which, so far as we know, do not produce disease in man.

As regards the ice from lakes and ponds, then, we may conclude that although the product from some of them contains a larger number of bacteria than is consistent with the highest standards of good sanitation, the conditions could be readily changed so as to render them quite unimpeachable, and in no case is there absolute reason, so far as the writer is aware, to fear contamination with forms which are known to be disease-producing; while in some cases, notably in the smaller ponds, the ice, so far as the analyses show, is well within the standard of absolute excellence.

The Hudson River ice stands, on the other hand, on an entirely different basis. Thoroughly contaminated with sewage at the upper part of the ice-fields, the water receives fresh accessions of bacterial impurities at various points near some of the ice-fields, which lie at a considerable distance from Albany.

Now, given ice from this source, in which the average number of bacteria per cubic centimetre is absolutely large, and a great degree of sewage pollution, we have to ask ourselves what is the actual danger which we have to fear from the use of the ice for drinking purposes.

A considerable number of the bacteria are undoubtedly the relatively or absolutely harmless species which may exist in any natural river or spring water, but a large number may, with equal certainty, be assumed to originate from animal excreta. Here, again, it is scarcely to be doubted, although not yet demonstrated, that a considerable proportion of the bacteria which exist in sewage coming from human and other animal excreta and the varied putrefying fluids which form a prominent ingredient in the waste of populous towns, may not be

positively dangerous if taken into the body in moderate quantities in drinking-water, and so far as such bacteria go, it would seem to be largely a matter of taste on the part of the consumer whether he uses such material for drinking purposes without purification or not. On the other hand, in every large town, such as Albany, and in smaller towns in lesser degree, there is more or less constantly passing into the sewers in the excreta or other wastage a considerable number of bacteria which are the cause of serious disease, and here it ceases to be a matter of individual preference, because the interests of the public health are involved.

There are some varieties of diarrhœal disturbance, sometimes mild, sometimes severe, particularly affecting persons who are sensitive in the matter of ingesta, which often seem to depend upon impurities in the drinking-water and in ice. Whether these are occasioned by sewage or other bacteria, or by organic matter in the water or ice, or by both, is not yet fully decided, so that we may leave this class of cases out of view for the present.

Fortunately cholera and anthrax, both bacterial diseases transmittible by drinking-water, are not ordinarily present in the sewage of the region which we are studying, so that these diseases also, which must not be ignored by those having the public health in charge, do not fall within the scope of the present study. But there are two very common and very important bacterial diseases which are almost constantly present in large towns like Troy and Albany, and frequently so in villages like many of those which lie along the upper Hudson. These are typhoid fever and the diseases associated with acute suppuration and the so-called blood-poisoning from wounds or pyæmia.

Now, it is unfortunately true, as the above researches show, that the bacteria causing these two forms of disease are markedly resistant to the temperature at which ice forms. The most important of these, and the one to which the writer has paid most attention in these studies, is the typhoid bacillus.

The health statistics of Albany do not show the number of cases of typhoid fever which occur in the city during the various months, but only the number of deaths from the disease. The deaths from this disease in the city of Albany, for the details of which I am indebted to Dr. Balch, Secretary of the State Board of Health of New York, during the months in which the ice on the Hudson is ordinarily forming, that is, from December to March, are as follows: From December, 1883, to March, 1884, 20; from December, 1884, to March, 1885, 14; from December, 1885, to March, 1886, 16. That is, an average of about 16 each season. Now the number of

deaths represents a varying number of actual cases of the disease, since the mortality is exceedingly variable. But if, in order to be on the safe side in estimating the actual number of cases, we take the highest rate of mortality which ordinarily occurs as thirty per cent., we find that the chances are, as judging from the statistics of the past three years, that there will be not far from fifty cases of typhoid fever whose excreta will pass directly into the Hudson River from Albany each year during the ice-forming season.

The writer is informed that in Albany, as in most American towns, both in the hospital and among private patients, there is no systematic disinfection of the typhoid discharges, which therefore enter the sewers with their myriads of bacteria in a living condition. That they are present in myriads and living in the discharges of typhoid fever patients is a well-known fact, which the writer has had abundant opportunity to observe in making cultures of them for diagnostic and other purposes.

Now, the bacteria of typhoid fever are capable, as has been shown by Frankland, by Wolfhügel and Riedel, and by Bolton, and confirmed by the writer, of living for a considerable period in water, and they may, according to Frankland and Wolfhügel and Riedel, even proliferate in the water, particularly if, as in sewage, there is organic matter present. We have seen from the above studies that when the bacteria of typhoid fever in the living condition become entangled in the ice and frozen a considerable proportion are destroyed, but also that a very significant remnant persists, living in the ice for long periods, and perfectly able, when thawed out and placed under favorable conditions, to go on growing and proliferating just as before their hibernation. Whether they may retain life indefinitely or not in ice we do not know, as one hundred and three days is the longest period during which they have been kept frozen.

Here, then, as it seems to the writer, is the positive source of danger in the use of the Hudson River ice directly for drinking purposes, without some form of purification, at least, until it can be ascertained at what distance below Albany, or other towns whose sewage drains into the river near the ice-fields, a safe degree of bacterial purification of the water from natural causes may have occurred.

It will undoubtedly be asked, if typhoid bacilli have been detected in the Hudson River ice. They have not, nor is it very probable that they will be, unless, possibly, by chance. For, in the first place, the search for particular species of bacteria in a large dilution, such as exists here, is an almost hopeless task, unless the species sought

for possesses biological characters and peculiarities in its mode of growth on the culture media or in its appearance under the microscope which would render its detection among many other forms comparatively easy. Unfortunately this is not the case with the typhoid bacillus, whose identification can be complete only after a long series of various tests, among which, as is well known to bacteriologists, the growth in potatoes is the most characteristic. In the second place, its growth on gelatin plates is slow, and mixed, as it must be in sewage, with many other species which rapidly fluidify the gelatin, the opportunity for the development of its colonies is not very favorable. It has been detected in several instances in water suspected to be the cause of outbreaks of typhoid fever,[17] but the conditions for its detection were more favorable than those which the Hudson River water presents with its large sewage dilution.

If we look, on the other hand, at the cases of typhoid fever as they are constantly occurring in New York and the adjacent towns where Hudson River ice is used, we do not find, and we should not expect to find, any marked excess of typhoid fever among those who habitually use ice for drinking purposes over those who do not, because the sanitary surroundings of the classes who do not habitually use ice for drinking purposes are so much less favorable, as a general rule, than those of the habitual ice-consumers, that other sources of infection, equally or even more efficient, would abundantly cover any revelation of the statistics.

If ice containing sewage contamination were the only means by which the typhoid-fever poison were conveyed from one individual to another, we might expect to find an indication of it in the statistics, but, unfortunately, it is not. We can only assume, as it seems to the writer, from what has been shown in these studies, that ice from some parts of the Hudson River, particularly near Albany, may contain, even in considerable numbers, living typhoid-fever bacilli, and so may furnish a means of propagating the disease. Whether this is a frequent or an infrequent occurrence we do not know. That it is not so important a factor in the transmission of the disease as to render the typhoid-fever statistics of New York worse than those of other towns whose residents use ice from cleaner sources, is certain.

But there is a considerable number of cases of typhoid fever, seen by every practising physician, in which the most painstaking examination of the sanitary surroundings of the victims and their personal contacts fails entirely to account for the occurrence of the disease. Some of these isolated cases of typhoid fever, whose origin is

otherwise unaccountable, may well be due to the ingestion of typhoid bacilli from sewage-contaminated ice.

It should be remembered in considering this, as all other bacterial diseases, that the bacteria themselves are only one factor in determining the disease. There is to be taken into the account also the number of the bacteria, that is, the size of dose, and the condition of predisposition of the individual.

Now, unfortunately we know nothing about the number of typhoid bacilli which may be necessary to induce the disease in man, and we are equally ignorant concerning the nature of the predisposing conditions in the individual.

So that, if we sum up what we really know about the relations of Hudson River ice to typhoid fever, we can only say that the facts show that it is certain that the ice from some parts of the river must contain the bacteria of typhoid fever, and that these may be taken into the system with ice-water in a living condition. Whether the necessary relationship between the number of bacteria thus taken and the condition of predisposition of the individual occurs frequently or infrequently, or ever occurs at all, we cannot positively say, but the grave character of the disease should warn us against indifference in the matter, and such measures should be taken as will secure the consumer of ice against even the possibility of such infection.

Such considerations as these are apt to be met by those calling themselves, often somewhat ostentatiously, "common-sense people" by what may be called the "ancestor," or experience argument, which in this case would consist in saying that they and their fathers have used ice from the Hudson River all their lives, and have never suffered from typhoid fever. This view is one which ignores the necessary relationship between predisposition and determining cause, and the ever-increasing complexity of sanitary problems in large and growing towns. If the upper Hudson were still in the condition which prevailed when Hendrick Hudson made his exploratory voyage along its wellnigh tenantless shores, the ancestor argument might not be without a very modest value. But it should not be forgotten that with each new resident on the shores of the Hudson the increment of danger regularly increases.

With the bacteria of suppuration and pyæmia, the Staphylococcus pyogenes, the case is less serious. The contact of ice with wounds is not frequent, and when occurring may be guarded from possible ill-effects by antisepsis. The probability of infection in other ways from ice containing the staphylococcus is remote, but its pres-

ence would always suggest unpleasant and perhaps dangerous possibilities.

As to the pollution of the river water and the ice with this species, it is only necessary to recall how many cases of acute suppuration may be found at any time in a city of the size of Albany, and how much of the discharge is apt to find its way into the sewers without efficient disinfection, and to refer to the above experiments which show the resisting power of the bacteria to cold.

Practical Suggestions.—We now come to the practical measures which, as these studies seem to show, should be established in order to guard against a not only possible, but a very probable source of danger in the Hudson River ice. The writer is fully impressed, and wishes that those who may interest themselves in this matter should also be, with the great and important private and corporate interests which are involved in the supply and consumption of ice. Nor would the writer wish in any measure to suggest by these studies a curtailment in the consumption of ice, even for drinking purposes.

The great value of ice for actual consumption, especially in the summer months, in our city, among all classes, can hardly be overrated. The improper and inordinate use of ice for drinking purposes, which undoubtedly not infrequently occurs, is an abuse which belongs with other forms of intemperance and does not concern us here.

Now the measures which might be adopted in view of the present condition of affairs are of two kinds: First, such as would come under the supervision of those having the public health in charge; and second, those which belong in the province of the individual consumer.

In the first place, it would seem necessary that the State Board of Health, or some other authorized body, should have full control of the ice-harvesting fields, and, by a system of inspection not less strict than that which should exist in the care of the ordinary water-supply, determine which, if any, of the sources of ice-supply are so situated as to imperil the health of consumers of the ice. In view of what we know this would be comparatively simple in all cases except that of the Hudson River. Here it would be necessary to establish, by a most thorough scientific examination, the distances from all existing sources of sewage pollution at which it might be safely assumed that the water had freed itself from bacteria and other impurities sufficiently to form safe ice. It might in this way be possible to remove any chance of danger by permitting the questionable or bad ice to be sold only for cooling purposes, if such a classification is practicable,

and thus not essentially interfere with the interests of the ice companies.

A compulsory system of disinfection of excreta in infectious diseases might be instituted here, as it is in other countries in which the purity of the water-supply is under constant supervision.

When we consider the measures which the individual consumer might adopt for the avoidance of possible danger from bad ice, it is evident, from what we have seen, that if he could be certain that his supply came only from the lakes and ponds now used for this purpose, he would secure for himself, so far as the writer can judge, a fair degree of immunity from probable danger.

Remembering that the larger and more responsible ice companies do not, so far as the writer is aware, cut ice in the immediate vicinity of Albany, but at a considerable, and in the majority of cases at a great, distance below, the householder may eliminate to a certain extent his hazard by finding out, as accurately as possible, just what part of the river his ice comes from.

Whatever the source of ice-supply, however, the large excess in bacterial content which, in almost all cases, the snow-layer harbors over that of the transparent or sparsely bubbly ice, would render imperative the avoidance of the snow-layer for any but cooling purposes. But it should still be borne in mind that perfectly transparent ice may harbor very large numbers of living bacteria, if formed from water in which they were abundant.

A variety of devices can be adopted in the use of ice for the cooling of drinking-water, such as pitchers which contain separate receptacles for the ice, the cooling of the water in refrigerators, etc., which the ingenuity of the individual might suggest.

Or recourse may be had to artificial ice made from pure water, which, as a great deal of experience in the matter has shown, may be furnished at a cost not very greatly exceeding that at which the natural ice is delivered.

This is already done in some of the Continental cities. Thus in Berlin, Germany, a company exists which furnishes artificial ice made from distilled water, which, as would be expected, is almost absolutely free from contamination.

Such water as is furnished by the Hygeia Distilled Water Company in New York would, if artificially frozen, make a most admirable and safe substitute for the natural ice.

The writer must be content, in this series of pioneer studies on the impurities of ice, with having, by experimental means, endeavored to give definiteness and

precision, not only to the problem in general, but to the detailed questions which arise in connection with the ice-supply of one particular town.

It would appear that we now know with tolerable certainty just what series of questions are to be answered, and investigations made, in order to decide upon the safety of any given source of ice-supply. But these detailed investigations can only be made under the sanction and direction of the public authorities.

It is unfortunate that a certain amount of perhaps entirely unjust opprobrium is now attached to all of the Hudson River ice, when it should perhaps belong only to that harvested in particular regions. It would therefore seem to the writer that it is greatly to the interest of the ice companies, as well as the public, that the State health authorities should take the matter of detailed examination of the Hudson River ice-fields at once in charge.

In conclusion, the writer wishes to express his sincere hope that this study may not be looked upon in a sensational light, nor regarded as a polemic against ice companies and dealers, or against the free and wonted use of ice, the incalculable usefulness of which is beyond question. A most thorough personal examination of the ice-harvesting and the practice and purpose of the more responsible dealers, lead to no other conclusion than that they are as desirous as could reasonably be expected of them to furnish a clean and pure product to the market, and, so far as facts have hitherto instructed them, have apparently done so. But in the clear light which the new methods of science throw upon the whole subject of important ice impurities, it seems necessary that a sweeping reform, in some respects, should speedily be brought about. This long and expensive series of researches has been carried out in the hope that in the light of its results the rapidly developing discipline of "preventive medicine" might find a plan of curtailing, in some degree, the number of annual victims to preventible disease.

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